Electronics practicals

Real world circuits applications

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UWIRINGIYIMANA Innocent

From Theories to Practicals

VISIT…

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Book with the same author

Step in electronics practicals;

"real world circuits applications" ISBN: 9781417491376

Preface

The study of electronics is one of the basic steps in gaining an understanding of all modern technology and science also; our everyday life depends a lot on the electronic. So, this book of electronics practicals provides a comprehensive and clear coverage of electronic practical concepts, practical applications and troubleshooting. In this book many topics have been strengthened and some topics, innovative and features have been added related to the real world. These practical topics are coordinated with the text showing working principles and their practical design and will make any candidate to be more effective in practical applications. Additionally, real world circuits design make the book more visually interesting and easier to use. The circuit provided have been simulated using reliable and accurate method and tested using real components.

This Electronics Practicals book will help to strengthen TECHNICAL and ENGINEERING EDUCATION with practical skills.

Features

- Math level is limited to basic algebra
- Full-color format
- A chapter opener includes a list of chapter objectives and website or book reference
- Numerous schematic circuits with their related circuits connection as they appear in real world

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Chapter one

Symbols, Units and Quantities

Objectives

When you have studied this chapter, you should

- Be familiar with the standard electrical and electronic circuit symbols
- Be familiar with base units and a variety of delivered units and quantities used in electronic
- Be able to analyse simple applications of the given SI units
- Be able to analyse scientific and engineering notation
- Have an understanding of electronic quantities and their relevance

Further reading
Study aids for this chapter are available at the companion website
• http://www.physics-help.info/physicsguide/appendices/si_units.shtml
• http://www.electronic-symbols.com/electronic-electrical-symbols/basic-electrical-electronic-symbols.htm

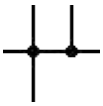
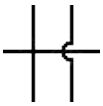
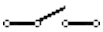
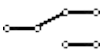
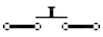
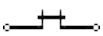
Circuit symbols are used for electronic circuit diagrams. The various symbols are used to represent different electronic components and devices in circuit diagrams from wires to batteries and passive components to semiconductors, logic circuits and highly complicated integrated circuits. By using a common set of circuit symbols in circuit diagrams, it is possible for electronic engineers around the globe to communicate circuit information concisely and without ambiguity. Although there are a number of different standards in use for the different circuit symbols around the globe, the differences are normally small, and because most systems are well known there is normally little room for ambiguity.

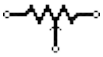
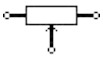
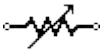
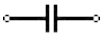
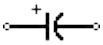
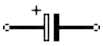
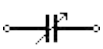
Scientific and engineering notation which are used to write numbers in compact form are represented in this chapter.

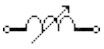
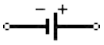
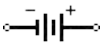
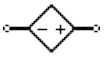
Electrical and electronics quantities of measurement are described in this chapter. These quantities are derivatives of the International System of Units. The SI base quantities make a set of mutually independent dimensions that are used in science and technology. However, in a given realization in these units they may well be interdependent, i.e. defined in terms of each other.

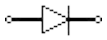
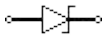
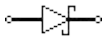
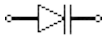
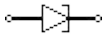
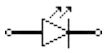
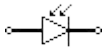
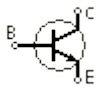
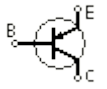
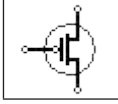
1. 1. Electrical and Electronic symbols

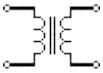
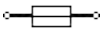
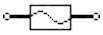
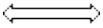
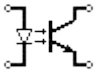
Table 1-1 describes the most commonly used electrical and electronic circuit symbols for drawing schematic diagram.

Symbol	Component name	Significance
Wire Symbols		
	Electrical Wire	Conductor of electrical current
	Connected Wires	Connected crossing
	Not connected Wires	No interconnection
Switch Symbols and Relay Symbols		
	Single Pole Single Throw Toggle Switch	Disconnects current when open
	Single Pole Double Throw Toggle Switch	Selects between two way connections
	Pushbutton Switch (N.O)	Momentary switch - normally open
	Pushbutton Switch (N.C)	Momentary switch - normally closed
	Single Pole Single Throw Relay	Relay open / close connection by applying an electromagnet
	Single Pole Double Throw Relay	
	Jumper	Close connection by jumper insertion on pins.
	Solder Bridge	Solder to close connection
Ground Symbols		
	Earth Ground	Used for zero potential reference and electrical shock protection.

	Chassis Ground	Connected to the chassis of the circuit
	Digital / Common Ground	Zero logic for digital circuits
Resistor Symbols		
	Resistor (IEEE)	Resistor restricts the flow of current.
	Resistor (IEC)	
	Potentiometer (IEEE)	Adjustable resistor - has 3 terminals.
	Potentiometer (IEC)	
	Variable Resistor / Rheostat(IEEE)	Adjustable resistor - has 2 terminals.
	Variable Resistor / Rheostat(IEC)	
Capacitor Symbols		
	Capacitor	Capacitor is used to store electric charge. It acts as short circuit with AC and open circuit with DC.
	Capacitor	
	Polarized Capacitor	Electrolytic capacitor
	Polarized Capacitor	Electrolytic capacitor
	Variable Capacitor	Adjustable capacitance
Inductor / Coil Symbols		
	Inductor	Coil / solenoid that generates magnetic field
	Iron Core Inductor	Coil includes iron

	Variable Inductor	Adjustable inductor
Power Supply Symbols		
	Voltage Source	Generates constant voltage
	Current Source	Generates constant current.
	AC Voltage Source	AC voltage source
	Generator	Electrical voltage is generated by mechanical rotation of the generator
	Battery Cell	Generates constant voltage
	Battery	Generates constant voltage
	Controlled Voltage Source	Generates voltage as a function of voltage or current of other circuit element.
	Controlled Current Source	Generates current as a function of voltage or current of other circuit element.
Meter Symbols		
	Voltmeter	Measures voltage. Has very high internal resistance. Connected in parallel.
	Ammeter	Measures electric current. Has near zero resistance. Connected serially.
	Ohmmeter	Measures resistance
	Wattmeter	Measures electric power
Lamp / Light Bulb Symbols		
	Lamp / light bulb	Generates light when current flows through
	Lamp / light bulb	

	Lamp / light bulb	Generates light when current flows through
Diode / LED Symbols		
	Diode	Diode allows current flow in one direction only (left to right).
	Zener Diode	Allows current flow in one direction, but also can flow in the reverse direction when above breakdown voltage
	Schottky diode	Schottky diode is a diode with low voltage drop
	Varactor / Varicap Diode	Variable capacitance diode
	Tunnel Diode (Esaki diode)	Very fast diode that can operate well into the microwave radio frequency region.
	Light Emitting Diode (LED)	LED emits light when current flows through
	Photodiode	Photodiode allows current flow when exposed to light
Transistor Symbols		
	NPN Bipolar Transistor	Allows current flow when high potential at base (middle)
	PNP Bipolar Transistor	Allows current flow when low potential is applied at base
	Darlington Transistor	Made from 2 bipolar transistors. Has total gain of the product of each gain.
	JFET-N Transistor	N-channel field effect transistor
	JFET-P Transistor	P-channel field effect transistor
	NMOS Transistor	N-channel MOSFET transistor
	PMOS Transistor	P-channel MOSFET transistor

Miscellaneous Symbols		
	Motor	Electric motor
	Transformer	Change AC voltage from high to low or low to high.
	Electric bell	Rings when activated
	Buzzer	Produce buzzing sound
	Fuse	The fuse disconnects when current above threshold. Used to protect circuit from high currents.
	Fuse	
	Bus	Contains several wires. Usually for data / address.
	Bus	
	Bus	
	Optocoupler / Opto-isolator	Optocoupler isolates connection to other board
	Loudspeaker	Converts electrical signal to sound waves
	Microphone	Converts sound waves to electrical signal
	Operational Amplifier	Amplifies input signal and provides an output with some mathematic operations
	Schmitt Trigger	Operates with hysteresis to reduce noise.
	Analog-to-digital converter (ADC)	Converts analog signal to digital numbers
	Digital-to-Analog converter (DAC)	Converts digital numbers to analog signal

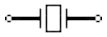
	Crystal Oscillator	Used to generate precise frequency clock signal
Antenna Symbols		
	Antenna / aerial	Transmits & receives radio waves
	Antenna / aerial	
	Dipole Antenna	Two wires simple antenna
Logic Gates Symbols		
	NOT Gate (Inverter)	Outputs 1 when input is 0
	AND Gate	Outputs 1 when both inputs are 1.
	NAND Gate	Outputs 0 when both inputs are 1. (NOT + AND)
	OR Gate	Outputs 1 when any input is 1.
	NOR Gate	Outputs 0 when any input is 1. (NOT + OR)
	XOR Gate	Outputs 1 when inputs are different. (Exclusive OR)
	D Flip-Flop	Stores one bit of data
	Multiplexer / Mux 2 to 1	Connects the output to selected input line.
	Multiplexer / Mux 4 to 1	
	Demultiplexer / Demux 1 to 4	Connects selected output to the input line.

Table 1-1: Electric and Electronic symbols

1. 2. Engineering Quantities and International Standard Units

The International System of Units (abbreviated SI from French: Le Système international d'unités) is the modern form of the metric system and is the world's most widely used system of measurement, used in both everyday commerce and science. It comprises a coherent system of units of measurement built around seven base units, 22 named and an indeterminate number of unnamed coherent derived units, and a set of prefixes that act as decimal-based multipliers. It is part of the International System of Quantities.

1. 2. 1. Base units

Base units are the building blocks of SI and all other units of measure can be derived from the base units. The seven base units are shown in table 1-2.

Unit name	Unit symbol	Quantity name	Dimension symbol
Metre	m	length	L
Kilogram	kg	mass	M
Second	s	time	T
Ampere	A	electric current	I
Kelvin	K	thermo dynamic temperature	Θ
Mole	mol	amount of substance	N
Candela	cd	luminous intensity	

Table 1-2: Base units

1. 2. 2. Quantities and Units in Electrical and Electronics

- **Volt (V or E)**

Volt is the electrical unit of voltage. Measuring unit of volt is represented by a letter V or E. One volt is the energy of 1 joule that is consumed when electric charge of 1 coulomb flows in the circuit.

$$1V = 1J / 1C$$

- **Ampere (A)**

Ampere is the electrical unit of electric current. Measuring unit of ampere is represented by a letter *I* or *i*. It measures the amount of electric charge that flows in an electrical circuit per 1 second.

$$1A = 1C / 1s$$

- **Ohm (Ω)**

Ohm is the electrical unit of resistance. Measuring unit of Ohm is symbolized by a latter R or a Greek letter Ω. For AC the resistance is said Impedance and is represented by a letter Z.

$$1\Omega = 1V / 1A$$

$$Z\ [\Omega] = \sqrt{(R^2+X^2)}$$

- **Watt (W)**

Watt is the electrical unit of electric power. It measures the rate of consumed energy.

$$1W = 1J / 1s$$

$$1W = 1V \bullet 1A$$

- **Decibel-milliwatt (dBm)**

Decibel-milliwatt or dBm is a unit of electric power, measured with logarithmic scale referenced to 1mW.

$$10dBm = 10 \bullet \log_{10} (10mW / 1mW)$$

- **Decibel-Watt (dBW)**

Decibel-watt or dBW is a unit of electric power, measured with logarithmic scale referenced to 1W.

$$10dBW = 10 \bullet \log_{10}(10W / 1W)$$

- **Farad (F)**

Farad is the unit of capacitance. Measuring unit is represented by a letter C. It represents the amount of electric charge in coulombs that is stored per 1 volt.

$$1F = 1C / 1V$$

- **Henry (H)**

Henry is the unit of inductance. Measuring unit symbol is represented by a letter H or L.

$$1H = 1Wb / 1A$$

- **Siemens (S)**

Siemens is the unit of conductance, which is the opposite of resistance. The measuring unit of conductance is represented by a letter G

$$1S = 1 / 1\Omega = 1Mho$$

- **Coulomb (C)**

Coulomb is the unit of electric charge.

$$1C = 6.238792 \times 10^{18} \text{ electron charges}$$

- **Ampere-hour (Ah)**

Ampere-hour is a unit of electric charge. One ampere-hour is the electric charge that flow in electrical circuit, when a current of 1 ampere is applied for 1 hour.

$$1Ah = 1A \bullet 1hour$$

One ampere-hour is equal to 3600 coulombs.

$$1Ah = 3600C$$

- **Tesla (T)**

Tesla is the unit of magnetic field.

$$1T = 1Wb / 1m^2$$

- **Weber (Wb)**

Weber is the unit of magnetic flux.

$$1Wb = 1V \bullet 1s$$

- **Joule (J)**

Joule is the unit of energy.

$$1J = 1\ kg \bullet 1(m / s)^2$$

- **Kilowatt-hour (kWh)**

Kilowatt-hour is a unit of energy.

$$1kWh = 1kW \bullet 1h = 1000W \bullet 1h$$

- **Kilovolt-amps (kVA)**

Kilovolt-amps is a unit of apparent power.

$$1kVA = 1kV \bullet 1A = 1000 \bullet 1V \bullet 1A$$

- **Hertz (Hz)**

Hertz is the unit of frequency. It measures the number of cycles per second.

$$1\ Hz = 1\ cycles / s$$

- **Volt-Ampere-Reactive (Var)**

Var is the unit of Reactive power and its measuring unit symbol is represented by a letter Q. In inductor or capacitor how much magnetic or electric field made by 1Ax1V is called the unit of reactive power.

$$1Var=1V•1A$$

$Q= V•I •\sin\theta$; This can be positive for inductance and negative for capacitance.

- **Ohm-meter (Ω·m)**

Ohm-meter is the unit of electrical Resistivity**.** Resistivity is symbolized by Greek small letter Rho "ρ".

$$1\ \Omega•m=1\Omega•1m$$

- **Siemens per meter (S/m)**

Siemens per meter is the unit of Conductivity. Measuring unit of conductivity is represented by Greek small letter sigma "σ"

$$1S/m=1siemence/1meter$$

- **Volts per meter (V/m)**

Volts per meter is the unit of Electric Field. Measuring unit of Electric Field is symbolized by a letter E.

$$1V/m=1Volt/1meter$$

- **Newton per coulomb (N/C)**

Newton per coulomb is the unit of Electric field. The unit of measuring of Electric Field is symbolized by a letter "E".

$$1N/C=1Newton/1Coulomb$$

- **Volt-meter (V·m)**

Volt-meter is the unit of Electric Flux. Measuring unit of Electric Flux is symbolized by "Φe".

$$1Vm=1Volt•1meter$$

The relationship between quantities can be written using words or symbols (letters), but symbols are normally used because they are much shorter.

For example V is used for voltage, *I* for current and *R* for resistance:

As a word equation: **voltage = current × resistance**

The same equation using symbols: **V = *I* × R**

1.2.3. Unit prefixes

Units' prefixes are letters added to unit names to produce multiple and sub-multiples of the original unit.

Standard prefixes for the SI units of measure												
Multiples	**Name**		**deca-**	**hecto-**	**kilo-**	**mega-**	**giga-**	**tera-**	**peta-**	**exa-**	**zetta-**	**yotta-**
	Prefix		da	h	k	M	G	T	P	E	Z	Y
	Factor	10^0	10^1	10^2	10^3	10^6	10^9	10^{12}	10^{15}	10^{18}	10^{21}	10^{24}
Fractions	**Name**		**deci-**	**centi-**	**milli-**	**micro-**	**nano-**	**pico-**	**femto-**	**atto-**	**zepto-**	**yocto-**
	Prefix		d	c	m	μ	n	p	f	a	z	y
	Factor	10^0	10^{-1}	10^{-2}	10^{-3}	10^{-6}	10^{-9}	10^{-12}	10^{-15}	10^{-18}	10^{-21}	10^{-24}

Table 1-3: Units prefixes

chap 1

All multiples are integer powers of ten and above a hundred or below a hundredth all are integer powers of a thousand. For example, kilo- denotes a multiple of a thousand and milli- denotes a multiple of a thousandth; hence there are one thousand millivolts to the volts and one thousand volts to the kilovolts. The prefixes are never combined, and multiples of the kilovolts are named as if the volt were the base unit. Thus a millionth of a volt is a microvolt, not a millimillivolt, and a millionth of a volt is a millivolt, not a microkilovolt.

Some of the units have a convenient size for electronics, but most are either too large or too small to be used directly so they are used with the prefixes. The prefixes shown with unit quantity make the unit larger or smaller by the value shown.

Examples:

$75\text{mA} = 75 \times 10^{-3}\ \text{A} = 75 \times 0.001\ \text{A} = 0.075\ \text{A}$

→Which is equal to 75 thousandths (75/1000) of an Ampere.

$22\text{nF} = 22 \times 10^{-9}\ \text{F} = 22 \times 0.000\ 000\ 001\ \text{F} = 0.000{,}000{,}022\ \text{F}$

→Which is equal to 22 millionths (22/1,000,000) of a Farad.

$56\text{M}\Omega = 56 \times 10^{6}\ \Omega = 56 \times 1{,}000{,}000\Omega = 56{,}000{,}000\Omega$

→This is equal to 56 million Ohm.

1. 3. Scientific and engineering notation

These two notations are similar in that they express the number in the form of a decimal number multiplied by 10 to some power.

- **Engineering notation**

Engineering notation represents the numbers in which the powers of ten must be multiples of three.

In electronics there is a need to represent very large numbers and very small numbers with accuracy and with ease, usually within the same circuit or problem. This notation allows us to communicate in written form as well as verbally with circuit values and properties more accurately and will allow us to perform mathematical calculations with greater straightforwardness.

Example: 15778.25

In Engineering Notation this number is written as: 15.77825×10^3

This number is of the form, where A is between and (or between and), and p is a multiple of 3.

Engineering notation is used in many physical and engineering applications because numbers often come with units. if the above quantity represented the number of volts, then you could express 15778.25 volts as 1.577825×10^4 volts, or more conveniently as 15.77825 kilovolts (kV). The metric prefixes are used commonly for those powers that are multiples of 3.

For example, in various scientific and engineering disciplines you can see the use of Gigavolts (GV), Megavolts (MV), Kilovolts (KV), volts (V), millivolts (mV), microvolts (uV), nanovolts (n V) and even picovolts (pV). But it is rare to see the use of decivolts (dV) or hectovolts (hV).

- **Scientific Notation**

Scientific notation is just a fancy name for floating point arithmetic or notation also known commonly as Power of Ten Notation and can be applied to any number. In scientific notation a single digit (value from 1 to 9) must be to the left of the decimal point and some number of digits to the right of the decimal point for accuracy. The number of digits to the right of the decimal point will vary depending on the science you are studying or the precision required for needed calculations. Usually the precision requirements will be between two and four digits; the last digit will need to be rounded. The last part of this notation will show times 10 raised to some power indicating the correct placement of the decimal point.

Example: 15778.25

In scientific notation is written as: 1.577825×10^4

This number is of the form, where A is between and (or between and -), and p is an integer.

Things to remember

- The power to 10 exponent is equal to the number of places the decimal point was moved. If the decimal point is moved to the left, the number of places is added to the current power of 10 exponent value. If the decimal point is moved to the right, the number of places is subtracted from the current power of 10 exponent value.
- Engineering notation, like scientific notation generally, can use the E notation, such that can be written as or. The "E" or "e" should not be confused with the exponential "e" which holds a completely different significance. In the letter case, it would be shown that:

$$3e^{-9} \approx 0.000\ 370\ 23.$$

Chapter two

Electronic Hand Tools

Objectives

When you have studied this chapter you should

- Be familiar with hand tools used in electronics
- Be capable to indentify a variety hand tools most encountered in electronics
- Be capable to maintain and proper use of specific electronic hand tools
- Be aware and able to purchase specific electronic hand tools to the specific task

Further reading
Study aids for this chapter are available at the companion website
http://www.slideshare.net/rodericklamban/basic-hand-tools-electronics-technology

Electronics has its own special tools and supplies. Before thinking on electronics machines repair and maintenance you need to know at first hand tools you will use and the role of each. Hand tools are extensions of our hands. When we misuse our hands, we experience pain. When we misuse hand tools, the possibility of injury to ourselves or people working around us increases considerably. Furthermore, using a tool incorrectly can damage the tool or even cause the tool to fail.

Using the correct tool for the job is the first step in safe hand tool use. Tools are designed for specific needs. That's why you'll find screwdrivers with various lengths and tip styles and pliers with different head shapes. Using any tool inappropriately is a step in the wrong direction. To avoid personal injury and tool damage, select the proper tool to do the job well and safely.

Quality professional hand tools will last many years if they are taken care of and treated with respect. Manufacturers design tools for specific applications. If you use your screwdriver as a chisel or a pry bar, you can't expect it to be in good shape when you actually need to drive a screw. Use tools only for their intended purpose. Many jobs require the use of insulated tools. Hand tools are often used in combination with lockout tag systems to ensure that the circuits are not live. Many insulated hand tolls like screw drivers and pliers must be clearly marked with official 1.000 Volt rating symbol. They also must meet IEC 60900 and ASTM F1505 standards. These tools are designed to reduce the chance of injury if the tool should make contact with an energized. In this chapter we are going to describe some of the electronics hand tools and their intended use.The hand tools described in this chapter are the most encountered from many electronics hand tools.

2. 1. Pliers

Pliers are a hand tools used to hold objects firmly, for bending, or physical compression and shaping wire. Generally, pliers consist of a pair of metal first-class levers joined at a fulcrum positioned closer to one end of the levers, creating short jaws on one side of the fulcrum, and longer handles on the other side. This arrangement creates a mechanical advantage, allowing the force of the hand's grip to be amplified and focused on an object with precision. The jaws can also be used to manipulate objects too small or unwieldy to be manipulated with the fingers.

2. 1. 1. Pliers Features and Benefits

- Lightweight, miniature pliers line. Includes versatile selection of diagonal, angular, tip and end cutters plus wiring and assembly tools.
- Choice of oval, tapered, relieved and angled head designs for general or confined area cutting.
- Full flush or semi-flush cutting edges machine ground and electronically hardened for extended life in cutting either hard or soft wires.
- Needle nose styles include long, short, curved, flat and round to handle most forming, looping, twisting, insertion and pickup jobs.
- Copaloy joint maintains perfect cutting edge and tip alignment to maximize operational consistency and tool life.
- Handle coil springs, standard on all Copaloy pliers, allow faster cutting action with reduced user fatigue.
- Forged from high quality alloy steel for maximum strength and durability.
- Precision ground to close tolerances, individually finished and tested to ensure exact fit of jaws.
- Polished heads with gun metal handles.

2. 1. 2. Cutting Edge Quality

The quality of a pair of cutting pliers can be determined by visual inspection. The blades should smoothly and evenly meet at the tips. From a point just behind the tips to the joint, an increasing amount of light should be visible. A precision tip interface assures clean cutting of fine wires, while the "no contact" area behind the tips extends cutter life by allowing the tips to continue to meet as they wear.

2. 1. 3. User first choice

User preference considerations can be a matter of personal preference. Handle shape, grip color, grip material, spring tension and leverage ratio are usually related to user comfort. Proper spring tension will allow pliers to open and close with minimum effort. Finally, pliers with high leverage ratio provide the greatest ease of use and the longest life.

There are many kinds of pliers made for various general and specific purpose and some useful ones in electronics are described in this chapter.

2. 1. 4. Transverse end cutting pliers

Transverse end flush cutter is ideal for vertical cutting in tight spaces.

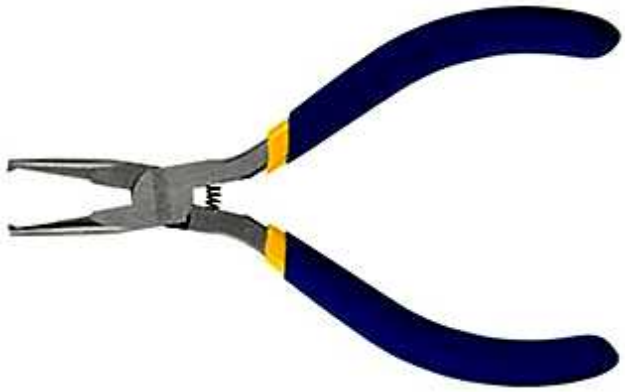


Figure 2-1: Transverse end cutting plier

2. 1. 5. Diagonal cutting pliers

Diagonal pliers (or wire cutters or diagonal cutting pliers or diagonal cutters) are pliers intended for the cutting of wire (they are generally not used to grab or turn anything). The plane defined by the cutting edges of the jaws intersects the joint rivet at an angle or "on a diagonal", hence the name. Instead of using a shearing action as with scissors, they cut by indenting and wedging the wire apart. The jaw edges are ground to a symmetrical "V" shape; thus the two jaws can be visualized to form the letter "X", as seen end-on when fully occluded. The pliers are made of tempered steel with inductive heating and quenching often used to selectively harden the jaws.

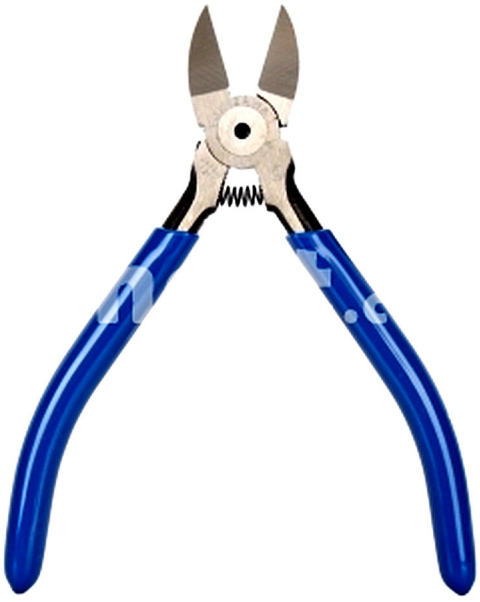


Figure 2-2: Diagonal cutting plier

The handles of diagonal cutting pliers are commonly insulated with a dip-type or shrink fit electrically-insulating material for comfort and some protection against electrical shock. Diagonal pliers are useful for cutting copper, brass, iron, aluminum and steel wire. Lower quality versions are generally not suitable for cutting tempered steel, such as piano wire, as the jaws are not hard enough. Attempting to cut such material will usually cause indentations to be made in the jaws, or a piece to break out of one or both jaws, thus ruining the tool. For electronics work, special diagonal cutters that are ground flush to the apex of the cutting edge on one side of the jaws are often used. These flush-cutting pliers allow wires to be trimmed flush or nearly flush to a solder joint, avoiding the sharp tip left by symmetrical diagonal cutters. It is common for this type of diagonal cutter to be referred to by another name, such as "flush cutter" to distinguish it from symmetrical cutters.

2. 1. 6. Long nose pliers with side cutter

Long nose pliers are used to hold things in small, awkward areas where your fingers will not fit. Long nose pliers are also used for bending, and stretching the lead of electronic component or connecting wires.

Figure 2-3: Long nose plier

2. 1. 7. Needle nose pliers

Needle-nose pliers (also known as pinch-nose pliers, or snipe-nose pliers) are both cutting and gripping pliers used by electricians and other tradesmen to bend, re-position and cut wire. Their namesake long gripping nose provides excellent control and reach for fine work in small or crowded electrical, while cutting edges nearer the pliers' joint provide "one-tool"convenience. Given their long shape, they are useful for reaching into cavities where cables (or other materials) have become stuck or unreachable to fingers or other means.

Figure 2-4: Needle nose plier

2. 1. 8. Round nose pliers

Round nose pliers because the bent jaws provide better access to tight areas. Especially useful for "tucking in" wire ends in beads. Cross section and taper is the same as chain nose pliers, but the jaws bend to one side.

Figure 2-5: Round nose plier

2. 2. Screwdriver

Screwdriver is a hand-tool used to turn, drive screws and sometimes bolts or other machine elements with a mating drive system.

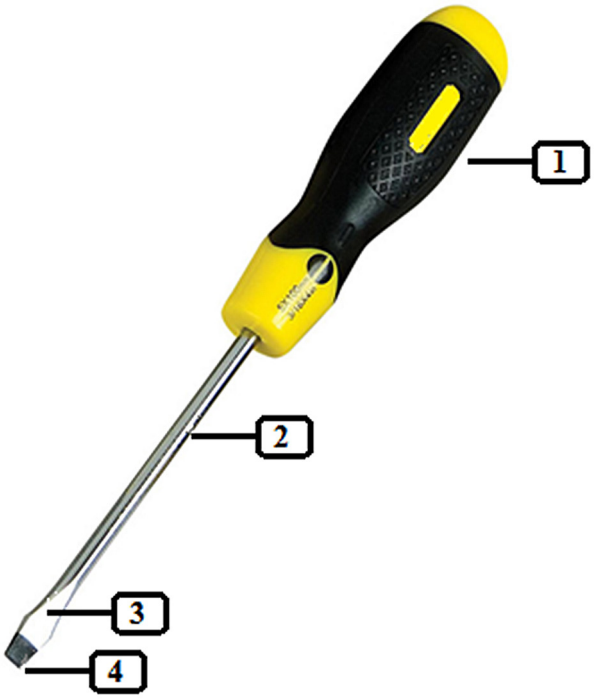


Figure 2-6: Screwdriver parts description

A typical screwdriver comprises:

1. **The handle:** A part which a person holds when using screwdriver. An approximately cylindrical handle of a size and shape to be held by a human hand.

2. **The shaft:** often called the shank. Narrow metal, often of cylindrical shape, embedded in and protruding from the handle. The handle and shaft allow the screwdriver to be positioned and supported.

3. **The blade:** The blade is located on the tip of the shank. The tip of the screwdriver with which a person turns a particular screw is generally referred to as the screwdriver blade. Screwdriver can be classified according to the shape of blade and the most popular styles are the flat head blade and the Phillips head blade.

4. **The tip:** Found at the end of the shaft, opposite the handle. By rotating the handle, torque is applied to the tip via the screwdriver's shaft.

2. 2. 1. User preferences

Quality screwdrivers are judged by the kind of metal in the blade, finish and amount of grinding

on the tip. Material used in the handle and bar attachment to the handle are other quality indicators.

If blade metal is poor quality, it will chip and crumble under pressure. If the tip is improperly ground and flares too much, it will rise out of the screw slot. If the blade is not attached firmly to the handle, it will eventually loosen and slip in the handle.

Use the right tip size. The tip of the screwdriver should completely fill the slot of the screw you are driving or removing. If the tip is too narrow, there will be considerable loss of leverage while driving, which means you will have to use more muscle to drive the screw. Also, you risk stripping the screw and bending the tip of your screwdriver. If the tip is too wide, you risk damaging the surface you are screwing into. If the tip is too thick, the blade will not fit in the screw slot and will just slip out as you are driving.

Figure 2-7: Screws shapes

Proper use of a screwdriver requires that the screwdriver's tip engages with the head of a screw having the same size and type designation as the screwdriver itself. Screwdriver tips are available in a large variety of shapes and sizes. Most screwdrivers, being hand-tools, are operated manually, but it is not uncommon to find screwdrivers that are operated by an electric motor or other motor.

2. 2. 2. Types of screwdrivers

Screwdrivers come in a large variety of sizes to match those of screws. Some screwdriver tips are magnetic, so that the screw remains attached to the screwdriver without requiring external force. This is particularly used in small screws, which are otherwise difficult to handle. Many screwdriver designs have a handle with detachable tip (the part of the screwdriver which engages with the screw), called bits as with drill bits, allowing a set of one handle and several heads to be used for a variety of screw sizes and types. Common types of screwdrivers most encountered in electronics and electrical are described below.

2. 2. 2. 1. Regular or Flat-head screwdriver

Flat-head screwdrivers are used with large, heavy screws and were the first type of screwdrivers to be developed, and for centuries it was the simplest and cheapest to make. Tip is flared so it is wider than the driver bar. Quality drivers with regular tips should be accurately ground for uniformity. Blades should not taper too sharply from the tip, because an improperly tapered tip has a tendency to rise out of the screw slot. The slot screw drive has a single slot in the fastener head and is driven by a flat-bladed screwdriver. The slotted screw is common in simple woodworking

applications, but is not often seen in applications where the power tool would be used because the power driver tends to slip out of the head and potentially damage the surrounding material.

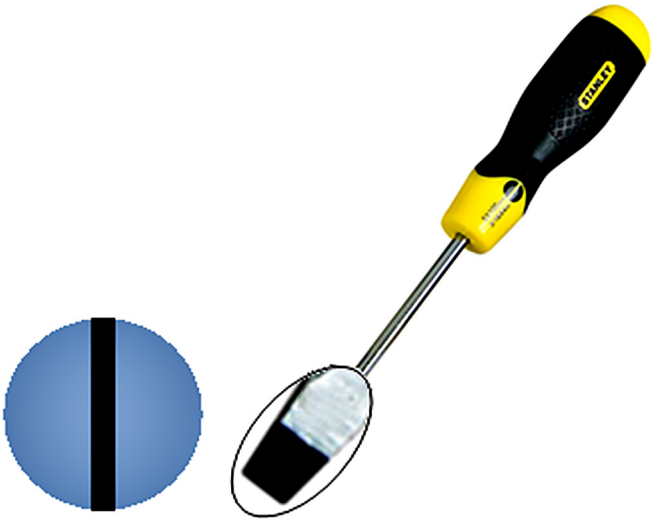


Figure 2-8: Flat-head screwdriver

The tool used to drive a slot is called a standard, flat-blade, slot-head, flat-tip, or the controversial name, flat-head screwdriver. This last usage can sometimes be confusing, because the term flat-head is also used to describe a screw with a flat top, designed to be installed in a countersunk hole. Such a flat-headed screw may have a slotted, cross, square recessed, or combination head, causing further confusion about the terminology.

2. 2. 2. 2. Cross-slot / Phillips

A cross-recess screw driver has two slots, oriented perpendicular to each other, in the fastener head; a slotted screwdriver is still used to drive just one of the slots. This type is usually found in cheaply made roofing bolts and the like, where a thread of 5 mm (0.20 inch) or above has a large flattened pan head. The sole advantage is to provide some measure of redundancy: should one slot be chewed up in service, the second may still be used.

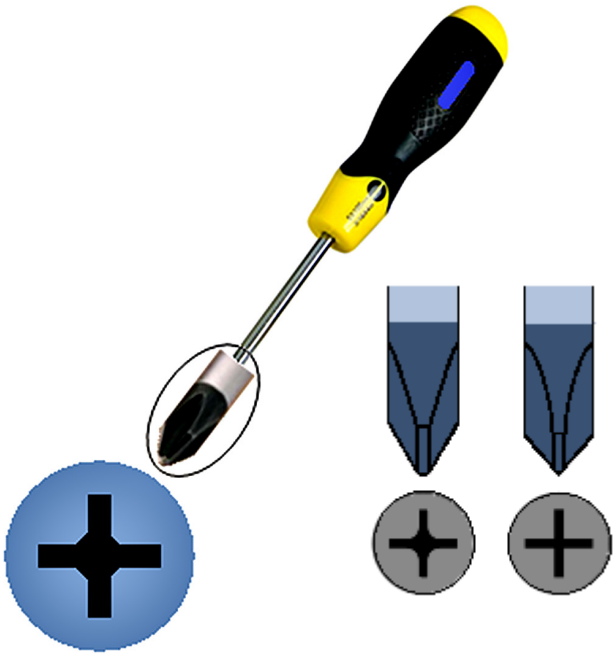


Figure 2-9: Phillips screwdriver

Phillips screwdriver was created by Henry F. Phillips. The Phillips screwdriver was purposely designed to cam out when the stalled, to prevent the fastener damaging the work or the head, instead damaging the driver. This was caused by the relative difficulty in building torque limiting into the early drivers.

The similar to the Phillips screw driver is the Frearson screwdriver which is shown on right. The Frearson screwdriver, also known as the Reed and Prince screwdriver, is similar to a Phillips but the Frearson has a more pointed 75° V shape. One advantage over the Phillips drive is that one driver or bit fits all screw sizes. The tool recess is a perfect, sharp cross, allowing for higher applied torque, unlike the rounded, tapered Phillips head, which was designed to cam out at high torque.

2. 2. 3. 3. Pozidriv

The Pozidriv, sometimes misspelled Pozidrive, screwdriver is an improved version of the Phillips screwdriver. It is jointly patented by the Phillips Screw Company and American Screw Company. The name is thought to be an abbreviation of positive drive. Its advantage over Phillips drives is its decreased likelihood to cam out, which allows greater torque to be applied. Phillips drivers have an intentional angle on the flanks and rounded corners so they will cam out of the slot before a power tool will twist off the screw head. The Pozidriv screws and drivers have straight sided flanks.

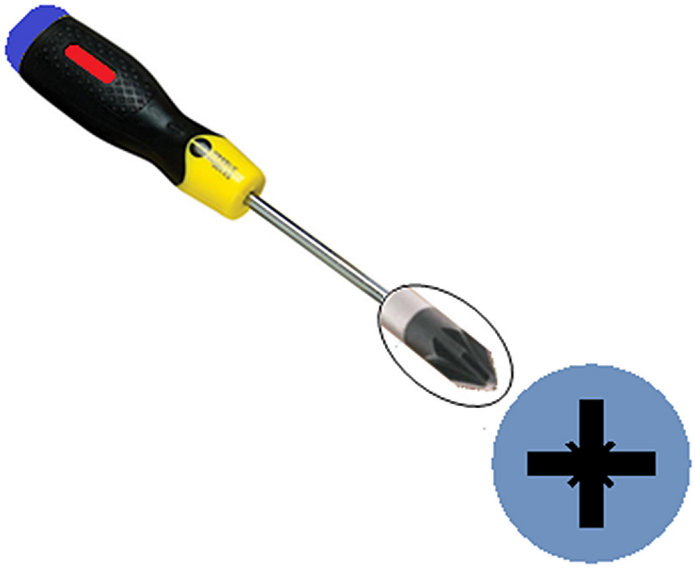


Figure 2-10: Pozidriv screwdriver

The Pozidriv screwdriver and screws are also visually distinguishable from Phillips by the second set of radial indentations set 45 degrees from the cross recess. The manufacturing process for Pozidriv screwdrivers is slightly more complex. The Phillips driver has four simple slots cut out of it, whereas in the Pozidriv each slot is the result of two matching processes at right angles. The result of this is that the arms of the cross are parallel-sided with the Pozidriv, and tapered with the Phillips.

This design is intended to decrease the likelihood that the Pozidriv screwdriver will slip out, provide a greater driving surface, and decrease wear. The principal disadvantage of Pozidriv screws is that they are visually quite similar to Phillips, thus many people are unaware of the difference or do not own the correct drivers for them, and use incorrect screwdrivers. This results in difficulty with removing the screw and damage to the recess, rendering any subsequent use of a correct screwdriver unsatisfactory. Phillips screwdrivers will fit in and turn Pozidriv screws, but will cam out if enough torque is applied, potentially damaging the screw head. The drive wings on a Pozidriv screwdriver will not fit a Phillips screw correctly, and are likely to slip or tear out the screw head.

2. 2. 2. 4. Hexagon screwdriver

A hexagon screwdriver uses six-sided fastener heads. The fastener is known as a hex head cap screw. It can be turned with an adjustable wrench, combination wrench, and 6- or 12-point sockets. The hex drive is better than square drive for locations where surrounding obstacles limit wrenching access, because smaller wrench-swing arcs can still successfully rotate the fastener.

Hex (hexagonal) tips are used in repair work in the electronics field, particularly in radio and television repair. They are used to tighten socket-set screws and usually come in sets. Some sets are attached to and fold into a metal carrying case.

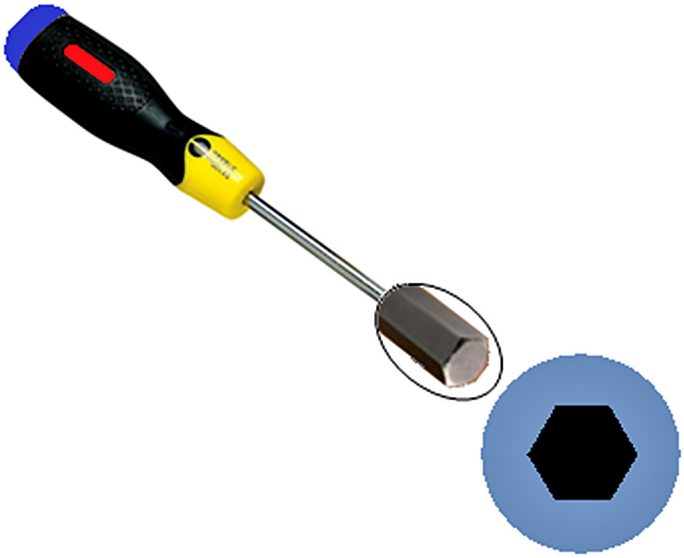


Figure 2-11: Hexagonal screwdriver

2. 2. 2. 5. Torx screwdriver

Torx drive system provides six lobular drive surfaces mated from lobes of the driving and driven elements. Drive surfaces have vertical sides that permit the maximum torque application to assure reliable clamping force. All driving torque is transmitted as a perpendicular force to the driven element so there is no cam-out.

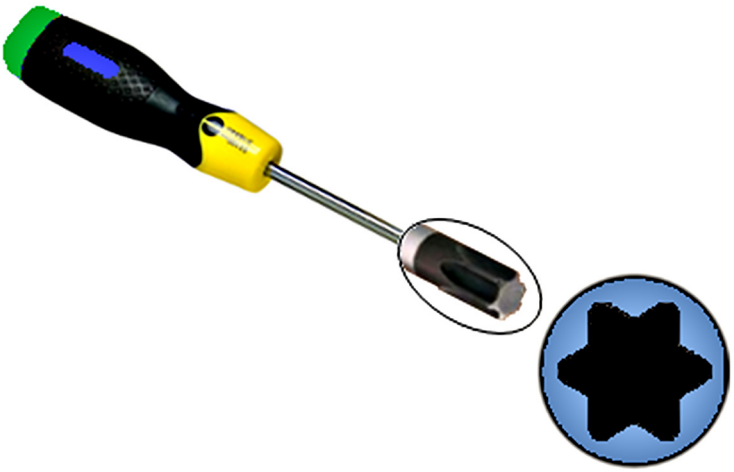


Figure 2-12: Torx screwdriver

2. 2. 2. 6. Multi-bit screwdrivers

Multi-bit screwdrivers allow the user to have a number of different types of tips in one tool. Some products keep the interchangeable bits in a self-contained unit. Offset screwdrivers are designed for removing and inserting screws in places where it is impossible to use a straight-shank screwdriver. They are available in many combinations of slotted and Phillips-head tips and with ratchet-type mechanisms. Many screwdrivers of this type have magnetized tips, convenient when guiding screws to holes or otherwise inaccessible areas. They also retrieve dropped screws and nuts. Others have split points that can be expanded in width to fill the screw slot and hold screws when guiding into inaccessible areas. A spring clamp that fits over the screw head, holding the bit

in the slot, serves a similar purpose.

If a screwdriver that is not the right size and type for the screw is used, it is likely that the screw will be damaged in the process of tightening it. This is less important for Pozidriv and Supadriv, which are designed specifically to be more tolerant of size mismatch. When tightening a screw with force, it is important to press the head hard into the screw, again to avoid damaging the screw.

Figure 2-13: Mult-bit screwdrivers

Many modern electrical appliances, if they contain screws at all, often use screws with heads other than the typical slotted or Phillips styles. Torx is one such pattern that has become very widespread. The main cause of this trend is manufacturing efficiency: Torx and other types are designed so the driver will not slip out of the fastener as will a Phillips driver. (Slotted screws are rarely used in mass-produced devices, since the driver is not inherently centered on the fastener.) A benefit or disadvantage of non-typical fasteners (depending on your point of view) is that it can be more difficult for users of a device to disassemble it than if more common head types were used, but Torx and other drivers are widely available.

2. 3. Wire stripper

A simple manual wire stripper is a pair of opposing blades much like scissors or wire cutters. The addition of a center notch makes it easier to cut the insulation without cutting the wire. This type of wire stripper is used by rotating it around the insulation while applying pressure in order to make a cut around the insulation. Since the insulation is not bonded to the wire, it then pulls easily off the end. This is the most versatile type of wire stripper. Another type of manual wire stripper is very similar to the simple design previously mentioned, except this type has several notches of varying size. This allows the user to match the notch size to the wire size, thereby eliminating the need for twisting. Once the device is clamped on, the remainder of the wire can simply be pulled out, leaving the insulation behind.

Figure 2-14: Wire stripper

2. 4. Tweezers

Tweezers are tools used for picking up objects too small to be easily handled with the human hands. They are probably derived from tongs, pincers, or scissors-like pliers used to grab or hold hot objects since the dawn of recorded history. In a scientific or medical context they are normally referred to as forceps. Tweezers are also used to hold, remove, and/or maneuver objects that are too small to be gripped with the hand.

There are two common forms of construction for tweezers:

Two fused, angled pieces of metal, or one piece of metal bent in half. The bent tweezers is cheaper to manufacture, but gives weaker grip. The fused tweezers is more expensive, but allows for a stronger grip. The width between the tips of the tweezers when no force is applied also affects how powerfully they grip.

Tweezers shapes and types

Tweezers come in a variety of tip shapes and sizes. Blunt tip tweezers have a rounded end which can be used when a pointed object may get entangled, when manipulating cotton swabs, for example.

2. 4. 1. Flat tip tweezers

Flat-tip tweezers have larger, wider tips useful for gripping larger electronic objects from circuit. Flat tip tweezers, pictured below, have an angled tip which may be used for removing splinters.

Figure 2-15: Flat tip tweezers

2. 4. 2. long needle-like tip and curved tweezers

Some tweezers have a long needle-like tip which may be useful for reaching into small crevices. Tweezers with curved tips also exist, sometimes called bent forceps.

Figure 2-16: Tweezers; Long needle-like (a) and curved (b)

2. 4. 3.Triangular tip tweezers

Triangular tip tweezers have an extremely small, pointed tip used for manipulating tiny electronic components and the like. Microtweezers have an extremely small, pointed tip used for manipulating tiny electronic components and the like.

Tweezers can be used for other tasks such as plucking hair from the face or eyebrows, and whenever small objects have to be manipulated, including for example small, particularly surface-mount, electronic parts, and small mechanical parts for models and precision mechanisms. Stamp collectors use tweezers (stamp tongs) to handle postage stamps which, while large enough to pick up by hand, could be damaged by handling; the jaws of stamp tongs are smooth. One example of a specialized use is picking out flakes of gold in gold panning. It also used in kitchens to remove bones from fillets of fish in a process known as pin boning. Other uses of the same principle are named tweezers; although such terms are not necessarily widely used their meaning is clear to people in the relevant field.

Figure 2-17: Triangular tip tweezers

E.g., Raman tweezers, which combine Raman spectroscopy with optical tweezers.

2. 5. Breadboard

Breadboards are often used to test new circuit designs because it is faster and easier to experiment on a breadboard than it is to solder (fuse in to place) circuit components. In the next tutorials, you will gain hands-on experience building and testing electronic circuits by creating a breadboard circuit with basic electronic components, and a battery or an AC supply. This will help prepare you for more advanced electronic projects.

- **Breadboard description**

A breadboard (protoboard) is a construction base for prototyping of electronics. The term is commonly used to refer to solderless breadboard (plugboard). The blue lines on the image on the right show how the sockets are connected. You can see that the vertical columns of holes labeled with a "+" are connected to each other, as are the columns of holes labeled with a "-". The columns labeled with a "+" are called the power bus, and you will connect one of them to a positive input voltage, such as the positive terminal of a 12V battery. One of the columns labeled with a "-" (the ground bus) will be attached to the negative terminal of the battery. Note that in each row (numbered 1 through 29) sockets "a" to "e" are connected to each other. And "f" to "j" are also connected to each other. These groups of connected sockets form a node. Figure 2-18 shows some of the parts of a breadboard, including a map of the connections between breadboard sockets.

- **Instructions for Working with Breadboards**

1. Use 22-gauge (0.33mm^2) solid wire.

a. If the wire is bigger, it could permanently deform the spring contacts in the bread-board sockets and make those sockets unreliable in the future.

b. Test probes from multimeters are definitely too big for the holes in breadboards.

2. Some breadboards have bus lines that run all the way from one end of the board to the other. Bus lines are the columns of sockets beneath the + and − signs located at the edges of the breadboard. If you are not sure how your specific breadboard is wired internally, use your multimeter to verify which groups of holes are connected. The breadboard may also come with a map of its connections. This map, if present, can usually be found in the breadboard's instructions.
3. Breadboards are not meant for high-current connections.
4. Breadboards are not meant for high-voltage circuitry.
5. Be careful not to push insulation down into the spring contact in the breadboard sockets, as this can lead to a bad connection. Only put the bare, un-insulated part of the wire into the breadboard socket.
6. Stripping too much insulation or leaving long component leads may create accidental connections in the air above the breadboard, if two wires accidentally touch.
7. Some parts, like diodes, have a direction. Adding a part in the wrong direction might damage it and make the circuit not work.
8. It is good practice to build up a circuit one stage at a time and to check the connections using continuity tester or ohmmeter (a multimeter set to measure resistance) before applying power.

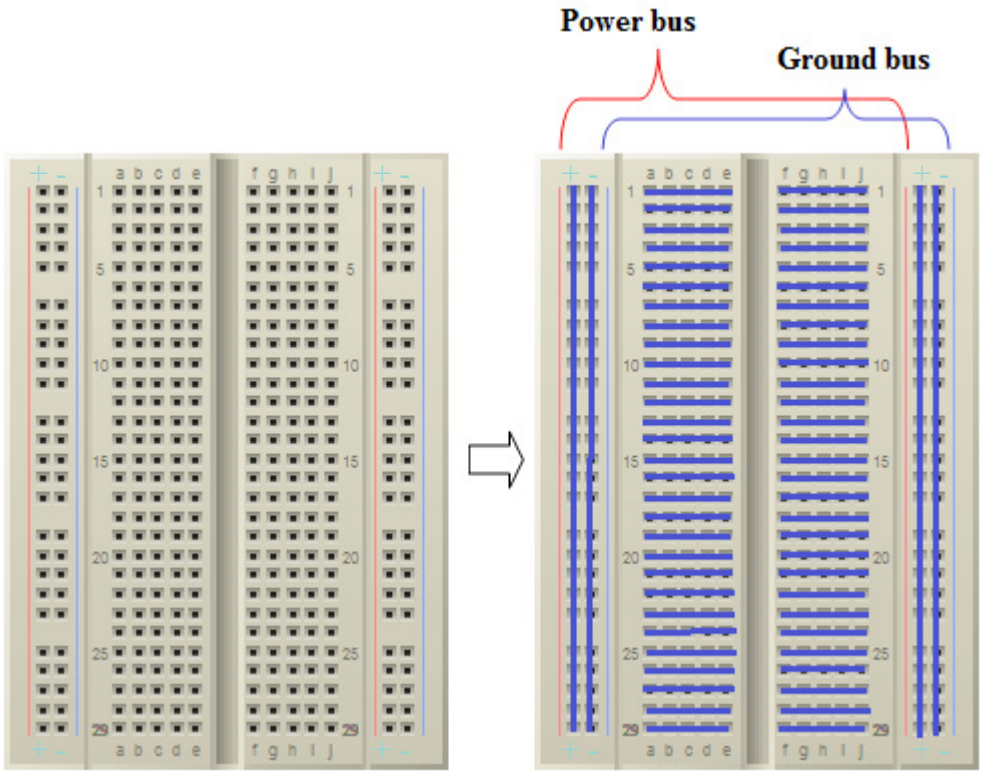


Figure 2-18: Breadboard description and connections map between breadboad sockets

Chapter three

Electronic Signal Generators and AC Supply

Objectives

When you studied this chapter, you should

- Be able to manipulate and use signal generators
- Be able to differentiate AC and DC source, draw and sketch the shape of the signal wave
- Be able to measure and calculate peak and peak-to-peak values
- Be able to measure and calculate period and frequency
- Be able to differentiate RMS value to Peak value

Further reading
Study aids for this chapter are available at
Bakshi, U. A.; Bakshi, A. V.; Bakshi, K. A. (2008). *Electronic Measurements and Instrumentation*. Pune, India: Technical Publications. pp. 3–26,3–27.

A sine signal generator provides variable frequency, low power, and variable voltage. The signal generator might have a cleaner sine wave. A signal generator is more likely to have an adjustable frequency and made adjustable more for facilitating other circuitry and less for matching some power requirement. The usual waveform of an AC power circuit is a sine wave. In alternating current (AC), the flow of electric charge periodically reverses direction, whereas in direct current (DC, also dc), the flow of electric charge is only in one direction. The abbreviations AC and DC are often used to mean simply alternating and direct, as when they modify current or voltage. In certain applications, different waveforms are used, such as triangular or square waves. Audio and radio signals carried on electrical wires are also examples of alternating current.

Mains AC power supply is a fixed-frequency 50Hz or 60Hz (depending on country) sine wave signal of high power and fixed voltage. The AC power outlet can likely deliver a lot more voltage (120V, 220V or 240 V r.m.s.) and a lot more current than any signal generator you can buy and, hence, a lot more power.

Being signal from function generator or from the main AC supply are characterized by their rms (root mean square) value, peak or peak-to-peak value, period and frequency, power, and current and voltage phase relationship. In this chapter we are going to describe how to measure and identify the peak, the peak-to-peak, the rms voltage, the period and frequency from a given waveform.

3. 1. The sinusoidal waveform

The sinusoidal waveform or sine wave is the fundamental type of alternating current (AC) and alternating voltage. It is also referred to as a sinusoidal wave, or, simply, sinusoidal. The electrical service provided by the power companies is in the form of the sinusoidal voltage and current. In addition, other types of repetitive waveform are composites of many individual sine waves called harmonics.

3. 1. 1. Identify a sinusoidal waveform and measure its characteristics

Sine waves, or sinusoids, are produced by two types of sources: rotating electrical machines (AC generators) or electronic oscillator circuits, which are used in instruments commonly known as electronic signal generators or function generators. The figure 3-1 shows the symbol used to present a source of sinusoidal voltage.

Figure 3-1: Symbol of Sinusoidal voltage source

The figure 3-2 is a graph that shows the general shape of a sine wave, which can be either an alternating current or an alternating voltage. Voltage (or current) is displayed on the vertical axis, and time (t) is displayed on the horizontal axis. Notice how the voltage (or current) varies with time. Starting at zero, the voltage (or current) increases to a positive maximum (peak), returns to zero, and then increases to a negative maximum (peak) before returning again to zero, thus completing on full cycle.

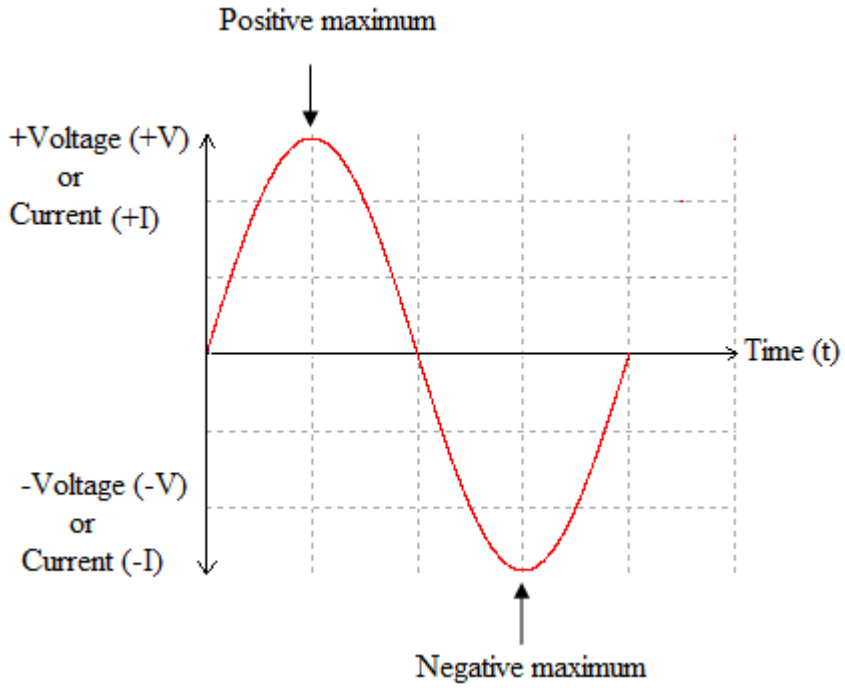


Figure 3-2: General shape of a sine wave

3. 1. 2. Polarity of a sine wave

As mentioned, a sine wave change polarity at its zero value; that is, it alternates between positive and negative values. When sinusoidal voltage source (Vs) is applied to a resistive circuit, an alternating current results. When the voltage changes polarity, the current correspondingly changes direction as indicated in figure 3-3 and figure 3-4.

During positive alternation of the source voltage Vs, the current is in the direction shown in the figure 3-3.

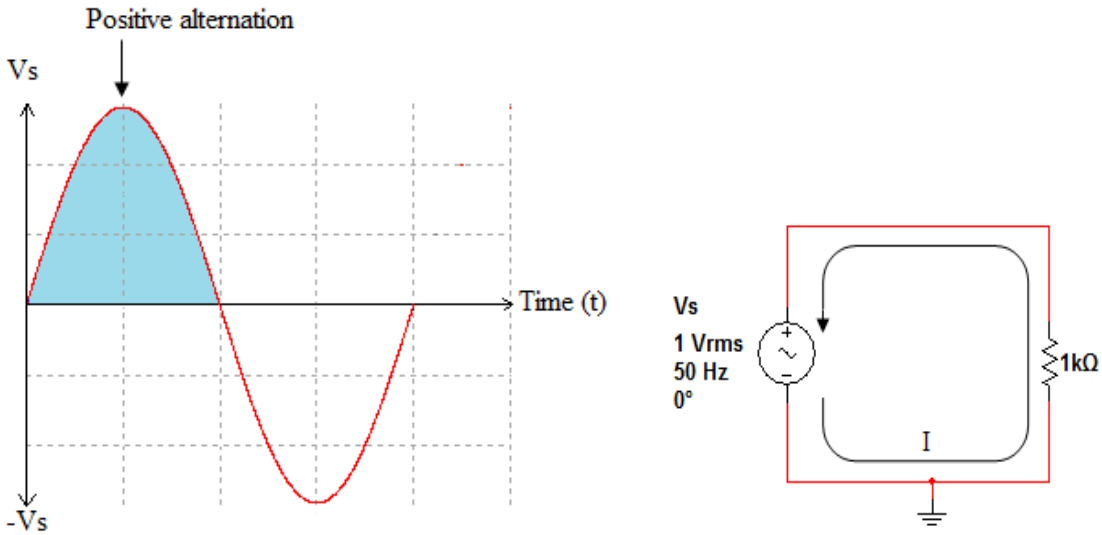


Figure 3-4: Direction of current during positive alternation

During negative alternation of the source voltage, the current is in the opposite direction, as shown in the figure 3-4. The combined positive and negative alternations make up one cycle of a sine wave.

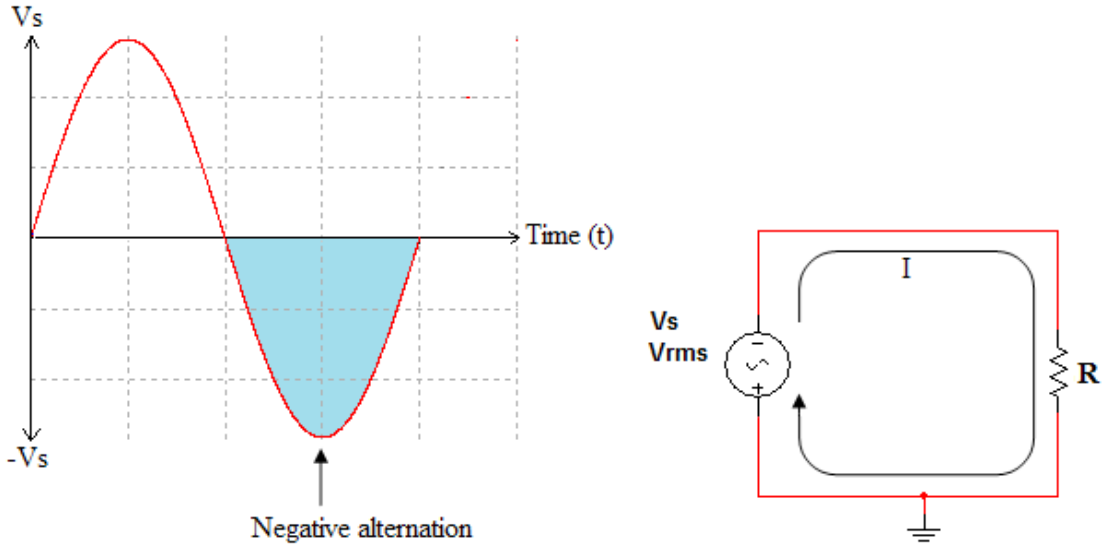


Figure 3-3: Direction of current during negative alternation

3. 1. 3. Period of a sine wave

A sine wave varies with time (t) in a definable manner. The time required for a given sine wave to complete one full cycle is called the period (T). Typically, a sine wave continues to repeat itself in identical cycles, as illustrated in the figure 3-5. Since all cycles of a repetitive sine wave are the same, the period is always a fixed value for a given sine wave.

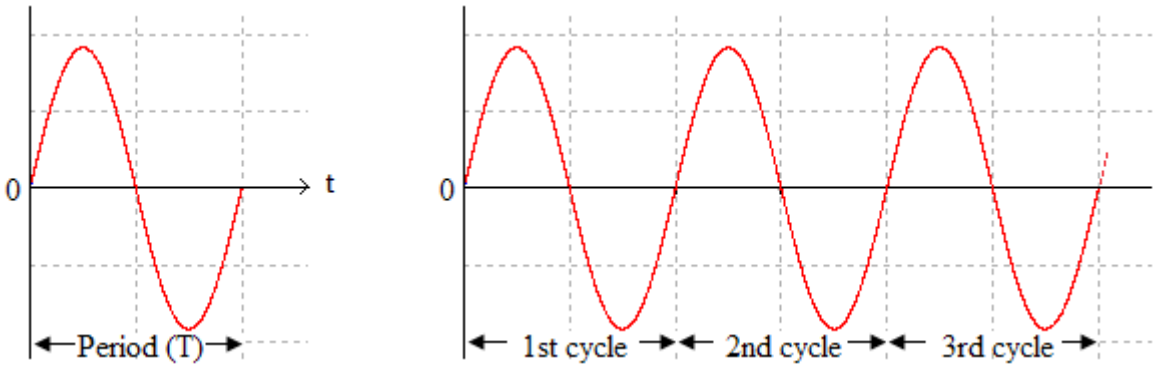


Figure 3-5: Periode for any number of cycles

The period of a sine wave can be measured from a crossing to the next corresponding zero crossing. The period can also be measured from any peak in a given cycle to the corresponding peak in the next cycle.

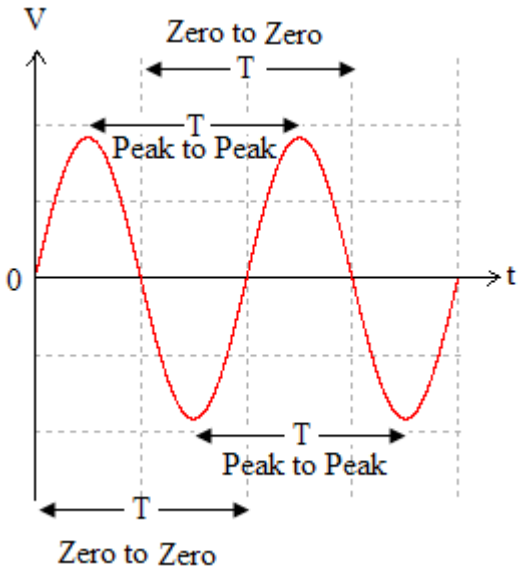


Figure 3-6: Period measuring technics

3. 1. 4. Frequency of a sine wave

Frequency is the number of cycles that a sine wave completes in one second. The more cycles completed in one second, the higher the frequency. Frequency (*f*) is measured in hertz (Hz). One hertz is equivalent to one cycle per second; for example, 50Hz is 50 cycles per second. The figure 3-7 shows two sine waves of different frequencies. The first one, figure 3-7 part (A), completes two

full cycles in one second. The second one, figure 3-7 part (B), completes four cycles in one second. Therefore, the sine wave of the second has twice the frequency of the first one.

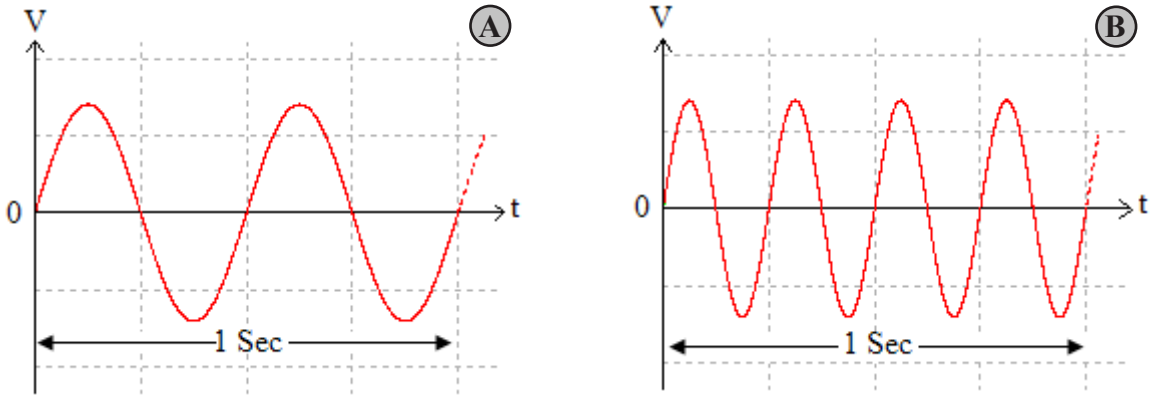


Figure 3-7: Frequency of a sine wave; (A) Lower frequency: fewer cycles per second, (B) Higher frequency: more cycles per second

3. 1. 5. Relationship of frequency and period

The formulas for relationship between frequency and period are:

$$f = 1/T$$

$$T = 1/f$$

There is a reciprocal relationship between *f* and T. knowing one, you can calculate the other with the x^{-1}or 1/x on the calculator. This inverse relationship indicates that a sine wave with a longer period goes through fewer cycles in one second than one with a shorter period.

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3. 1. 6.Voltage and current of a sine wave

Five ways to express and measure the value of a sine wave in terms of its voltage or its current magnitude are instantuous, peak, peak-to-peak, rms, and average value.

- **Peak value**

The peak value of a sine wave is the value of a voltage (current) at the positive or negative maximum (peaks) with respect to zero. Since positive and negative peak values are equal in magnitude, a sine wave is characterized by a single peak value, as illustrated in the figure 3-8. For a given sine wave, the peak value is constant and is represented by Vp or *I*p. In the figure 3-8 the peak value is 8V.

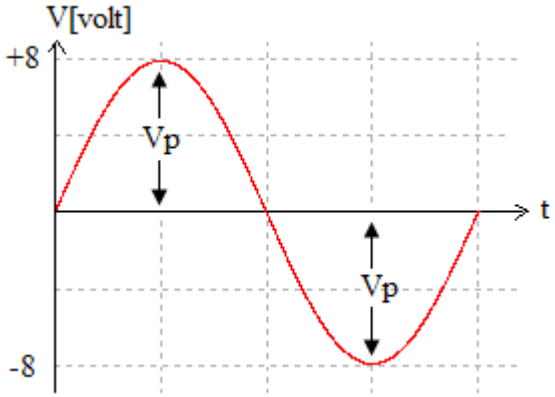


Figure 3-8: Measuring Peak value of a sine wave

- **Peak-to-peak**

The peak-to-peak of a sine wave is the voltage (or current) from the positive to the negative peak. It is always the twice the peak value as illustrated by the following equations. Peak-to-peak values are represented by V_{pp} or I_{pp}

$$V_{pp}=2V_p \qquad \text{[Equation 3-1]}$$

$$I_{pp}=2I_p \qquad \text{[Equation 3-2]}$$

For the figure 3-9, the peak-to-peak value is 16V

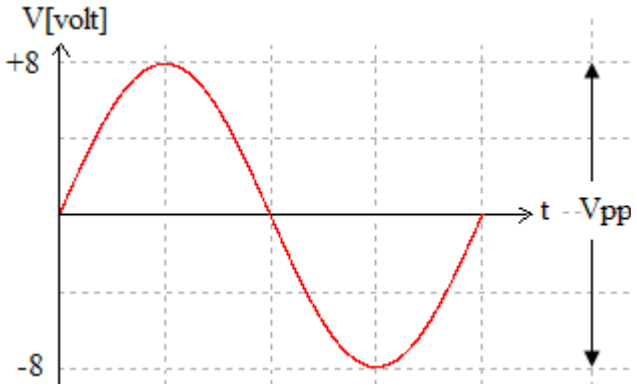


Figure 3-9: Measuring peak-to-peak on a sine wave

- **RMS value**

The term rms stand for root mean square. Most of voltmter display the rms voltage. The 220V at the wall outlet is an rms value. The rms, also refered to as the effective value, of a sinusoidal voltage is actually a measure of the heating effect of the sine wave. For example, when a resistor is connected across an AC (sinusoidal) voltage source, a certain amount of heat is generated by the power in the resistor.

3. 2. Electronic Signal Generators

The signal generator is an instrument that electronically produces sine waves for use in testing or controlling electronic circuits and systems. There are a variety of signal genarators, ranging from special-purpose instruments that produce only type of waveform in a limited frequency range to programmable instruments that produce a wide range of frequencies and a variety of waveforms. All signal generators consist basically of an oscillator, which is an electronic circuit that produces sinusoidal voltages or other types of waveforms whose amplitute and frequency can be adjusted.

Function generator and arbitrary waveform generators

The function generator provides pulse waveforms as well as sine waves and triangular waves. The arbitrary waveform generator can be used to genarate standard signals like sine waves, triangular waves, and pulse waves as well as signals with various shapes and characteristics. Waveforms can be defined by mathematical or graphical input.

a) **Agilent 33120A Function generator description and user's guide**

1. Function/modulation keys
2. Menu operation keys
3. Waveform modify keys
4. Single/internal trigger key (Burst and sweep only)
5. Recall/store instrument state key
6. Enter number key
7. Shift/rocal key
8. Enter number key

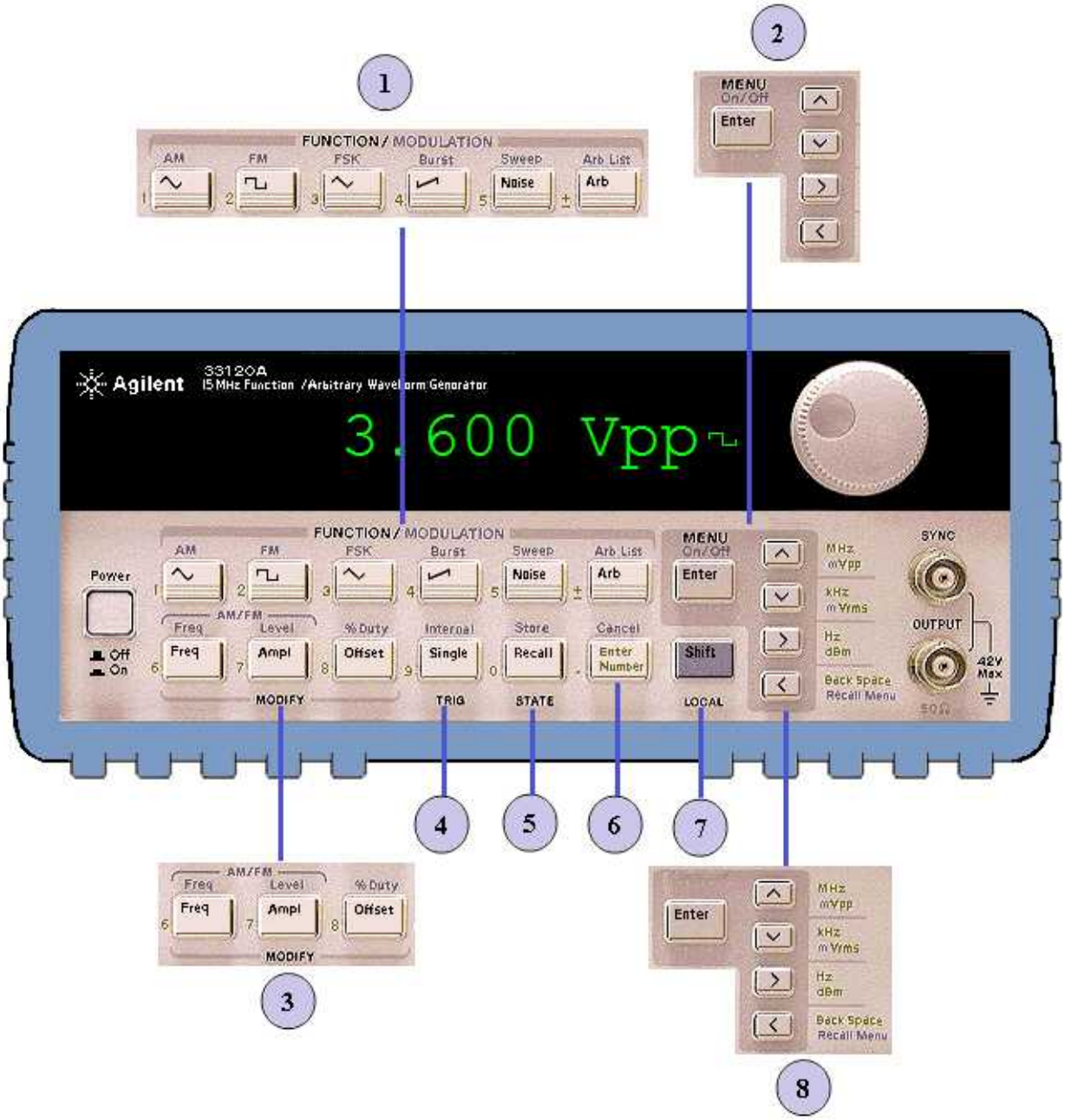
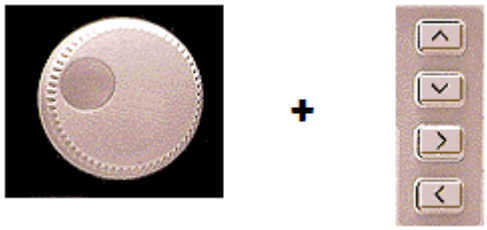


Figure 3-10: Agilent Function generator 33120A front view pannel

b) **You can enter number from front-pannel by using one of the three methods.**

1. Using the knob and the allow keys to modify the displayed number



2. Use the allow keys to modify the individual number

Increaments the flashing digit.

Decreaments the flashing digit.

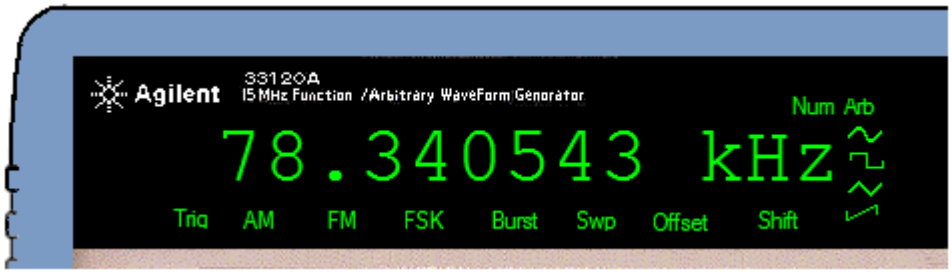
Moves the flashing digit to the right.

Moves the flashing digit to the left.

3. Use the "enter" number mode to enter a number with the appropriate units

Use the "enter" for those operations that do not require units to be specified (AM level, Offset, % duty, and Store /Recall state)

c) **Display annunciators**



Adrs Function generator is addressed to listen or talk over a remote interface
AM AM modulation is enabled
Arb Arbitrary wavefom function is enabled.
Bust Burst modulation is enabled
ERROR Hardware or remote interface command errors are detected

Ext	Function generator is set for an external modulation dource (AM, FSK, Bust)
FM	FM modulation is enabled
FSK	FSK (Frequency-shift keying) modulation is enabled
Num	"enter number" mode is enabled. Press "shift-cancel to disable.
Offset	The waveform is being output with an offset voltage
Rmt	Function generator is in remote mode (remote interface)
Shift	"shift" key has been pressed . press "shift again to turn off"
Swp	Sweep mode is enabled
Trig	Function generator is waiting for a single trigger or external trigger (Burst, sweep)
∿	Sine waveform function is enabled
⊓	Square waveform function is enabled
∿	Triangle waveform function is enabled
⟋	Ramp waveform function is enabled

To review the display annunciators, hold down the Shift "shift" key as you turn on the function generator.

d) **The rear pannel at a glance**

1. Chassis ground
2. Power-line fuse-holder assembly
3. Power-line voltage setting

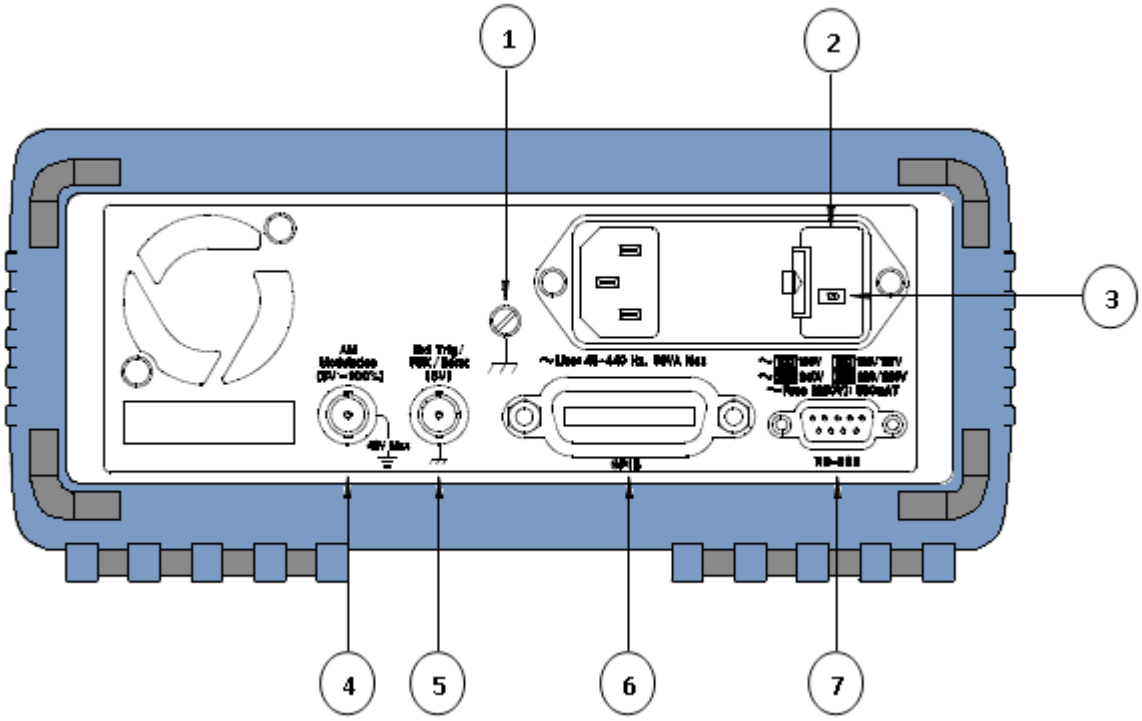


Figure 3-11: The rear pannel at a glance of 33120A agillent function generator

4. AM modulation input terminal
5. External Trigger / FSK /Burst modulation input terminal
6. GPIB (IEEE-488) interface connector
7. RS-232 interface connector

Hands on tip

Two basic methods of generating sinusoidal voltages are electromagnetic and electronic. Sine waves are produced electromagnetically by ac generators and electronically by oscillator circuits.

3. 3. Direct Current and Alternating Current Supply

A power supply is a device that provides power to a load. A load is any electrical device or circuit that is connected to the output of the power supply and draws current from the supply. Electrical supplies can be direct current (DC) or alternating current (AC). Below notes describe difference between direct current (DC) and alternating current (AC) electrical supply.

3. 3. 1. Direct Current

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If the current flows in only one direction it is called direct current (DC). Batteries and cells supply DC electricity, a typical two batteries supply around 3 V (1.5V each). Batteries convert chemical energy into electrical energy. Because of their limited source of chemical energy, batteries have a certain capacity that limits the amount of time over which they can produce a given power. This capacity is measured in ampere-hours (Ah).

Figure 3-12: Size of common batteries. AA Cell (A) and Batteries DC source (B)

A battery is a type of DC source that converts chemical energy into electrical energy. A battery consists of one or more electromechanical cells that are electrically connected together internally.

The materials used in battery cell determine the voltage that is produced. Although the voltage of a battery cell is fixed by its chemistry, the capacity is variable and depends on the quantity of materials in the cell. Also the way the cells are connected and the type of cells determine the voltage and capacity of the battery. If the positive is connected to the negative of the next and so on, the battery voltage is the sum of the individual cell voltage. This is called *series connection*.

DC batteries are most encountered in domestic electronics appliances such as post redio, remote control, torch, etc,. The figure 3-13 shows circuit arrangement of the torch.

When batteries are placed in a flashlight, they are connected in series-aiding arrangement to provide a larger voltage as illustrated in flashlight example. In this example, four 1.5V batteries are placed in series to produce a total voltage $V_{s(total)}$ of 6V.

$$V_{s(total)}=V_{B1}+V_{B2}+V_{B3}+V_{B4}=1.5V+1.5V+1.5V= 6V$$

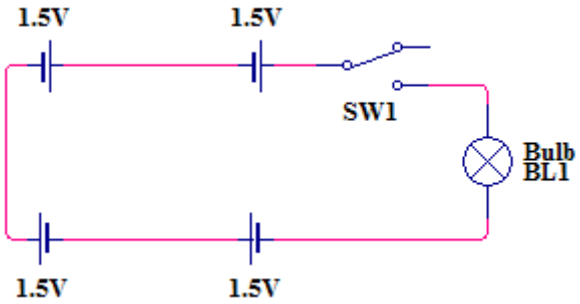


Figure 3-13: Torch circuit

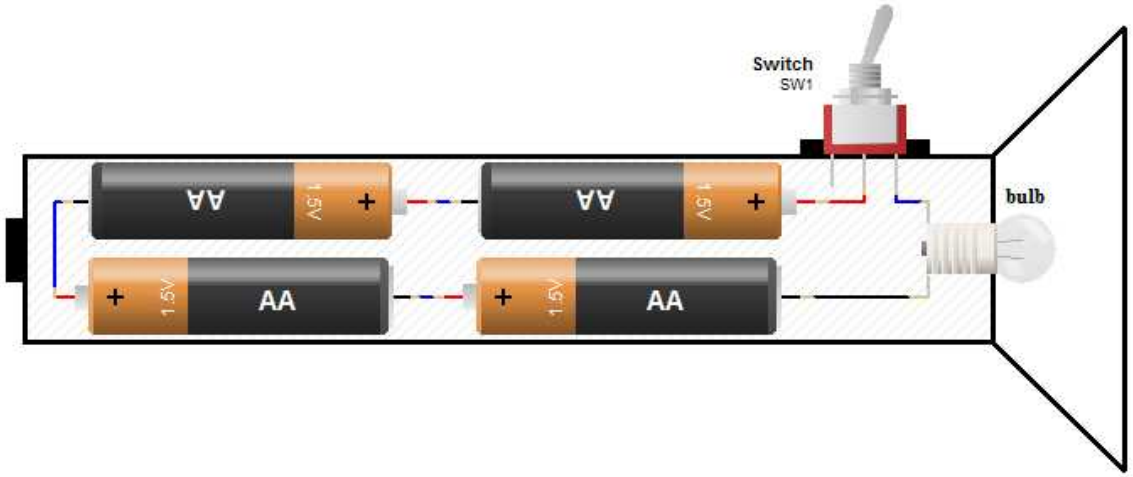


Figure 3-14: Torch circuit connection

To increase battery capacity, the positive of several cells are connected together and all the negatives are connected together. This is called parallel connection.

Also, by using larger cells, which have a greater quantity of material, the ability to supply current can be increased but the voltage is not affected.

Batteries are divided into two major classes, primary and secondary. Primary batteries are used once and discarded because of their chemical reactions are irreversible. Secondary batteries can be recharged and reused many times because they are characterized by reversible chemical reactions. There are many types, shapes, and sizes of batteries. Some of the size that you are most famil-

iar with are AAA, AA, C, D and 9V. There is also a less common size called AAAA, which is smaller than the AAA.

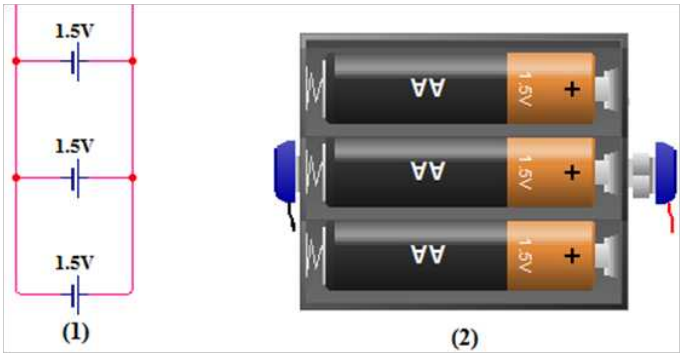


Figure 3-15: Parallel connected batteries; (1) Schematic circuit, (2) Circuit connection

Ampere-hour ratings of batteries

Because of their limited source of chemical energy, batteries have a certain capacity that limits the amount of time over which they can produce a given power level. This capacity is measured in ampere-hours (Ah). The ampere-hour rating determines the length of time that a battery can deliver a certain amount of average current to a load at the rated voltage.

A rating of one ampere-hour means that a battery can deliver an average of one ampere of current to a load for one hour at the rated voltage output. This same battery can deliver an average of two amperes for one-half hour. The more current the battery is required to deliver; the shorter the life of the battery. In practice, a battery usually is rated for a specified current level and output voltage. For example, a 12V automobile battery may be rated for 70Ah at 3.5A. This means that it can deliver an average of 3.5A for 20h at the rated voltage.

Apart of the batteries, DC source include Solar cells, Generators, Thermocouples, Piezoelectric sensors and the Electronic Power Supply (rectifiers). The later is discussed in the next chapters.

3. 3. 2. Alternating current

If the current flows in both directions (positive and negative direction alternatively) it is called Alternating current (AC). Synchronous generators and Function generators are examples of AC supply.

The sinusoidal waveform or sine wave is the fundamental type of alternating current (AC) and alternating voltage. It is also referred to as a sinusoidal wave, or, simply, sinusoidal. The electrical service provided by the power companies is in the form of the sinusoidal voltage and current. In addition, other types of repetitive waveform are composites of many individual sine waves called harmonics.

Sine waves, or sinusoids, are produced by two types of sources: rotating electrical machines (AC generators) or electronics oscillator circuits, which are used in instruments commonly known as electronic signal generators or function generators.

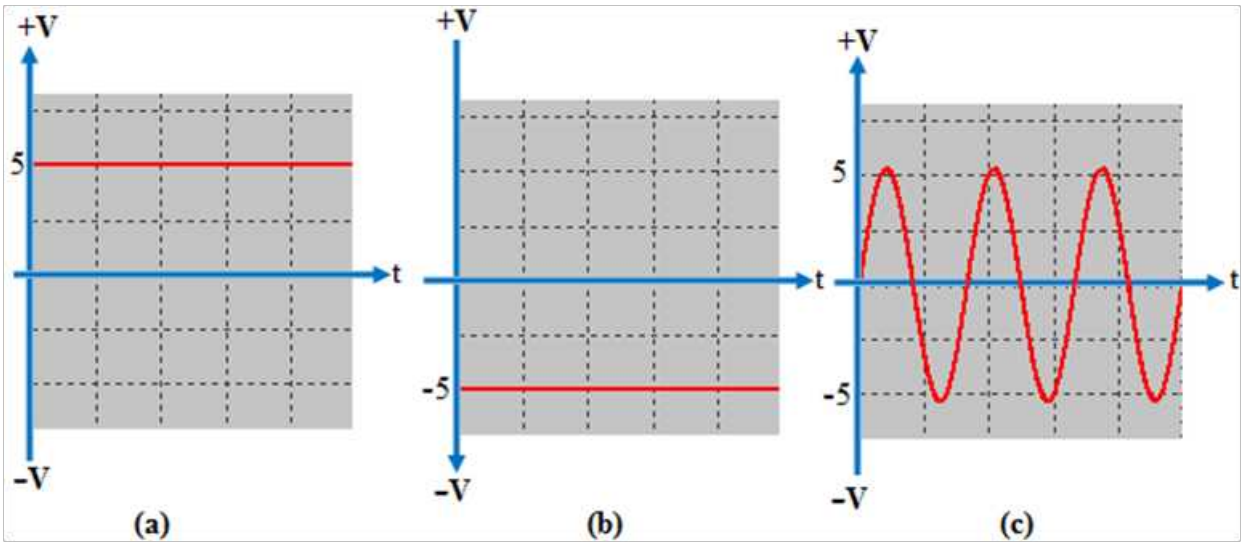


Figure 3-16: DC voltage and AC voltage shapes; (a) Positive DC voltage, (b) Negative DC voltage, (c) AC voltage oscillates both in positive and negative direction in function of time

The diagram, figure 3-17, shows an oscilloscope screen displaying the signal from an AC supply.

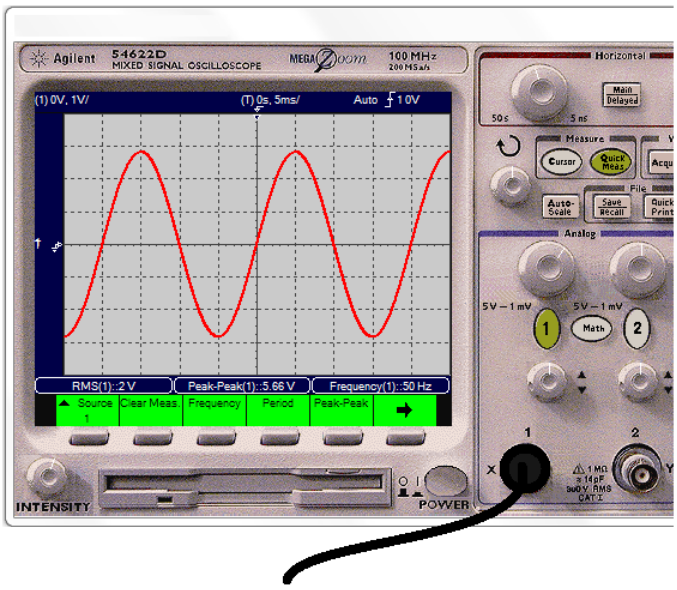


Figure 3-17: Oscilloscope displaying the signal from an AC source

chap 3

Hands on tip

An electronic power supply provides both output voltage and current. You should make sure the voltage range is sufficient for your applications. Also, you must have sufficient current capacity to assure proper circuit operation. The current capacity is the maximum current that a power supply can provide to a load at a given voltage. The power supply efficiency is the ratio of the output power, (Pout), to the input power, (Pin), and is often expressed as a percentage.

Chapter four

Basic Electronic Measuring Instruments

Objectives

When you have studied this chapter, you should

- Be able for proper use of Voltmeter, Ammeter, Ohmmeter and oscilloscope
- Be aware and fault diagnosis while measuring
- Be able to calibrate multimeter and oscilloscope with respect to the quantity to be measured
- Be able to measure Peak and Peak-to-Peak voltage using oscilloscope
- Be able to measure Period and frequency using oscilloscope

Further reading
Study aids for this chapter are available at the companion website
http://webphysics.davidson.edu/Course_Material/Py230L/oscopes/scopes.htm

In developing electronics circuits, assembly and in electronics experiment practical requires the use of many different kinds of electronic test equipment ranging from the very simple and inexpensive to extremely complex and sophisticated. Generally, more advanced test instrument is necessary when developing circuits and systems than is needed when doing production testing, testing experimental circuit or when troubleshooting existing production units in the field. Measuring and testing instruments are required to analyze, diagnose and measure different quantities of electrical signal.

Measuring and testing instrument that we use to test and troubleshooting experimental circuit include, ammeter that measures current, voltmeter that measures voltage, ohmmeter that measures resistance, continuity tester to examine connectivity, function generator to deliver a reference signal, and oscilloscope whose essential is to display voltages which vary rapidly with time.

Multimeters contain Ohmmeters, Voltmeters, Ammeters and a variety of capabilities to measure other quantities. AC and DC voltages are most often measurable. Multimeters also feature a continuity detector, basically an Ohmmeter with a beeper if the multimeter sees less than dedicated ohm value, 50Ω for example, then it beeps otherwise it is silent. This is very useful for finding whether components are connected when debugging or testing circuits. Multimeters are also often able to measure capacitance and inductance. This may be achieved using a Wien bridge. A diode tester is also generally onboard; this allows one to determine the anode and cathode of an unknown diode. A LCD display is also provided for easily reading of results. In this chapter we are going to illustrate the use of electronics basic testing and measuring instruments.

4. 1. Multimeter

A multimeter is an electronic measuring instrument that combines several measurement functions in one unit and is also known as a multitester or VOM (Volt-Ohm meter). A typical multimeter would include basic features such as the ability to measure voltage, current, and resistance. Multimeter can be analog or digital.

4. 1. 1. Analog multimeter

Analog multimeters use a microammeter whose pointer moves over a scale calibrated for all the different measurements that can be made. Resolution of analog multimeters is limited by the width of the scale pointer, parallax, vibration of the pointer, the accuracy of printing of scales, zero calibration, number of ranges, and errors due to non-horizontal use of the mechanical display. The figure 4-1 represents the analog multimeter display. Mirrored scales and larger meter movements are used to improve resolution; two and a half to three digits equivalent resolution is usual (and is usually adequate for the limited precision needed for most measurements).

Figure 4-1: Analog ammeter screen

Resistance measurements, in particular, are of low precision due to the typical resistance measurement circuit which compresses the scale heavily at the higher resistance values. Inexpensive analog meters may have only a single resistance scale, seriously restricting the range of precise measurements. Typically an analog meter will have a panel adjustment to set the zero-ohms calibration of the meter, to compensate for the varying voltage of the meter battery.

Analogue multimeter description

- **The dial**: It has the arc-shaped scales visible through the window. The pointer indicates values read from the scale.
- **The pointer or needle**: This is the thin black line at the left-most position in the dial face window in the image. The needle moves to the value measured.
- **Arc shaped lines or scales on the meter dial face**: These may be different colors for each scale, but will have different values. These determine the ranges of magnitude.

- **A wider mirror-like surface shaped like the scales** mentioned previously might also be present. The mirror is used to help reduce parallax viewing error by lining up the pointer with its reflection before reading the value the pointer is indicating. In the image, it appears as a wide gray strip between the red and black scales.
- **A wider mirror-like surface shaped like the scales** mentioned previously might also be present. The mirror is used to help reduce parallax viewing error by lining up the pointer with its reflection before reading the value indicated by the pointer. In the image, it appears as a wide gray strip between the red and black scales.
- **A selector switch or knob**: This allows changing the function (volts, ohms, amps) and scale (x1, x10, etc.) of the meter. Many functions have multiple ranges. It is important to have both set correctly, otherwise serious damage to the meter or harm to the operator may result. Most meters employ the knob type like the one shown in the image, but there are others. Regardless of the type, they work similarly. Some meters (like the one in the image above) have an "Off" position on this selector switch while others have a separate switch to turn off the meter. The meter should be set to "Off" when stored.

Figure 4-2: Analog ammeter (A) and its connecting leads (B)

- **Jacks or openings in the case to insert test leads**. Most multimeters have several jacks. The one pictured has just two. One is usually labeled "COM" or (-) ,for common and negative. This is where the black test lead is connected. It will be used for nearly every measurement taken. The other jack(s) is labeled "V" (+) and the Omega symbol (an upside down horseshoe) for Volts and Ohms, respectively, and positive. The + and - symbols represent the polarity of probes when set for and testing DC volts. If the test leads were installed as suggested, the red lead would be positive as compared to the black test lead. This is nice to know when the circuit under test is not labeled + or -, as is usually the case. Many meters have additional jacks that are required for current or high-voltage tests. It is equally important to have the test leads connected to the proper jacks as it is to have the selector switch range and test type (volts, amps, ohms) set. All must be correct. Consult the meter manual if you're unsure which jacks should be used.
- **Test leads**: There should be two test leads or probes. Generally, one is black and the other red. Black probes is considered as negative whereas the red probe as positive.
- **Battery and fuse compartment**: Usually found on the reverse, but sometimes on the side. This holds the fuse (and possibly a spare), and the battery that supplies power to the meter for resistance tests. The meter may have more than one battery and they may be of different sizes. A fuse is provided to help protect the meter movement. Sometimes there is more than one fuse. A good fuse is required for the meter to function. Fully charged batteries will be required for resistance/continuity tests.
- **Zero Adjustment**: This is a small knob usually located near the dial that is labeled "Ohms Adjust", "0 Adj", or similar. This is used only in the ohms or resistance range, while the probes are shorted together (touching each other). Rotate the knob slowly to move the needle as close to the 0 position on the Ohms scale as possible. If new batteries are installed, this should be easy to do - a needle that will not go to zero indicates weak batteries that should be replaced.

4. 1. 2. Digital multimeters

Digital multimeters sometimes abbreviated (DMM or DVOM) display the measured value in numerals, and may also display a bar of a length proportional to the quantity being measured. Digital multimeters are now far more common than analog ones, but analog multimeters are still preferable in some cases, for example when monitoring a rapidly-varying value.

A multimeter can be a hand-held device useful for basic fault finding and field service work, or a bench instrument which can measure to a very high degree of accuracy. They can be used to troubleshoot electrical problems in a wide array of industrial and household devices such as electronic equipment, motor controls, domestic appliances, power supplies, and wiring systems.

Quantities measured by multimeter

Modern multimeters can measure many quantities. The common ones are:

- Voltage: alternating and direct, in volts.
- Current: alternating and direct, in amperes.
- Resistance, in ohms.

The frequency range for which AC measurements are accurate must be specified.

Additionally, some multimeters measure:

- Capacitance in farads.
- Conductance in siemens.
- Decibels.
- Duty cycle as a percentage.
- Frequency in hertz.
- Inductance in henrys.

Digital multimeters may also include circuits for:

- Continuity tester; sounds when a circuit conducts
- Diodes (measuring forward drop of diode junctions), and transistors (measuring current gain and other parameters)
- Battery checking for simple 1.5 volt and 9 volt batteries. This is a current loaded voltage scale which simulates in-use voltage measurement.

Figure 4-3: Digital multimeter (A) and connecting leads (B)

Modern multimeters are often digital due to their accuracy, durability and extra features. In a digital multimeter the signal under test is converted to a voltage and an amplifier with electroni-

cally controlled gain preconditions the signal. A digital multimeter displays the quantity measured as a number, which eliminates parallax errors.

Modern digital multimeters may have an embedded computer, which provides a wealth of convenience features. Measurement enhancements available include:

- **Auto-ranging**, which selects the correct range for the quantity under test so that the most significant digits are shown. For example, a four-digit multimeter would automatically select an appropriate range to display 1.234 instead of 0.012, or overloading. Auto-ranging meters usually include a facility to hold the meter to a particular range, because a measurement that causes frequent range changes can be distracting to the user. Other factors being equal, an auto-ranging meter will have more circuitry than an equivalent non-auto-ranging meter, and so will be more costly, but will be more convenient to use.
- **Auto-polarity for direct-current readings**, shows if the applied voltage is positive (agrees with meter lead labels) or negative (opposite polarity to meter leads).
- **Sample and hold**, which will latch the most recent reading for examination after the instrument is removed from the circuit under test.
- **Current-limited tests for voltage drop across semiconductor junctions**. While not a replacement for a transistor tester, this facilitates testing diodes and a variety of transistor types.
- **Simple data acquisition features**, to record maximum and minimum readings over a given period, or to take a number of samples at fixed intervals.

A multimeter is also used to check for AC or DC voltage, resistance or continuity of electrical components and small amounts of current in circuits. This instrument will let the user to check if there is voltage present on a circuit, etc. Here is how to measure those values by using multimeter.

4. 1. 3. Voltmeter

Voltage is always measured in parallel within the circuit or direct to the terminals of the battery. This is due to the high internal resistance that a voltmeter has. Here below we describe general procedures for voltage measuring by using Volts Function of multimeter.

1. Set the meter for the highest range provided for AC Volts. Many times, the voltage to be measured has a value that is unknown. For this reason, the highest range possible is selected so that the meter circuitry and movement will not be damaged by voltage greater than expected. If the meter were set to the 50 volt range and a common system electrical outlet were to be tested, the 220 volts present could irreparably damage the meter. Start high, and work downward to the lowest range that can be safely displayed.
2. Insert the black probe in the “COM” or “-” jack.
3. Insert the red probe in the “ΩV” or “+” jack.
4. Locate the voltage scales. There may be several Volt scales with different maximum values. The range chosen by the selector knob determines which voltage scale to read. The maximum value scale should coincide with selector knob ranges. The voltage scales, unlike the Ohm scales, are linear. The scale is accurate anywhere along its length.

It will of course be much easier accurately reading 24 volts on a 50 volt scale than on a 250 volt scale, where it might look like it is anywhere between 20 and 30 volts.

5. Test a common electrical outlet. In many countries you might expect 220 volts or even 380 volts. In other places like in U.S., 120 or 240 volts might be expected.

Figure 4-4: Test electrical wall outlet using voltmeter

- Press the black probe into one of the straight slots. It should be possible to let go of the black probe, as the contacts behind the face of the outlet should grip the probe, much like it does when a plug is inserted.
- Insert the red probe into the other straight slot. The meter should indicate a voltage very close to 120 or 240 volts (depending on type outlet tested).
- Remove the probes, and rotate the selector knob to the lowest range offered, that is greater than the voltage indicated (120 or 240).
- Reinsert the probes again as described earlier. The meter may indicate between 110 and as much as 125 volts this time for 120 outlet system and 210 to 230 for 220 outlet system. The range of the meter is important to obtain accurate measurements.
- If the pointer did not move, it is likely that DC was chosen instead of AC. The AC and DC modes are not compatible. The correct mode must be set. If not set correctly, the user would mistakenly believe there was no voltage present. This could be deadly.

- Be sure to try both modes if the pointer does not move. Set meter to AC volts mode, and try again.
- Whenever possible, try to connect at least one probe in such a way that it will not be required to hold both while making test. Some meters have accessories that include alligator clips or other types of clamps that will assist doing this. Minimizing your contact with electrical circuits drastically reduces that chance of sustaining burns or injury.

Experiment 4-1: Measuring Voltage

a) Measuring the voltage of the battery

Voltage is always measured in parallel within the circuit or direct to the terminal of the battery. To start with something simple, let's measure voltage on an AA cell battery.

Part list

No	Item	Specification	Quantity
1	Voltmeter	Digital Multimeter	1
2	DC battery	Cell AA 1.5V battery	1

Figure 4-5: Measuring Voltage of an AA cell battery

Steps:

1. Pull out your multimeter and plug the black probe into COM (common) jack and the red probe into VΩ.

2. Set the multimeter to “2V” in the DC range (DC is a straight line, AC is the wavy line).
3. Squeeze the probes with a little pressure against the positive and negative terminals of the AA battery.
4. The black probe is customarily connected to ground or **“-”**and red goes to power or **“+”**. If you have got a fresh battery, you should see around 1.5V on the display.

b) **Testing voltage in a circuit**

The voltage across a component is a measure of the difference in electrical potential from one side of the component to the other and so the meter must be connected as shown in the following experiment.

Experiment 4-2: Measuring Voltage in a circuit

Part list

No	Items	Specifications	Quantity
1	Resistor	560Ω	1
2	Wire	22-gauge solid wire	10 cm
3	Breadboard	Prototyping board	1
4	Battery	9V dc supply	1
5	Diode	Light emitting diode	1

Let’s start with simplified circuit containing one resistor and a battery as shown in figure 4-6.

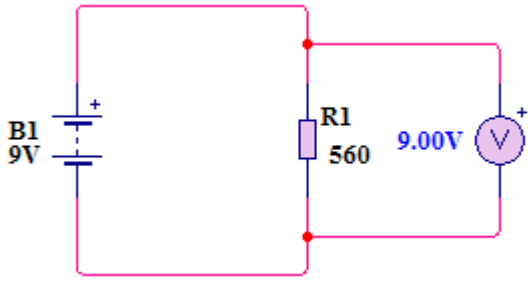


Figure 4-6: Measuring Voltage in a simplified circuit

Steps:

1. Set the multimeter to read “direct current (DC) voltage”. DC voltage does not alternate from positive to negative and is represented by this symbol ”V⎓” on multimeter. Check that the two probes are inserted into the correct holes to measure DC voltage i.e. plug the black probe into COM (common) jack and the red probe into VΩ.
2. Set multimeter to “20” DC voltage scale.

3. Touch the probes against the terminal ends of a fresh 9V battery. You should get a reading of approximately 9 V. The battery has a positive and a negative pole. Note that the multimeter also has a positive and a negative probe. If you attach the positive probe to the negative side of the battery, it will still read out 9 V, but it will have a negative sign in front of it.

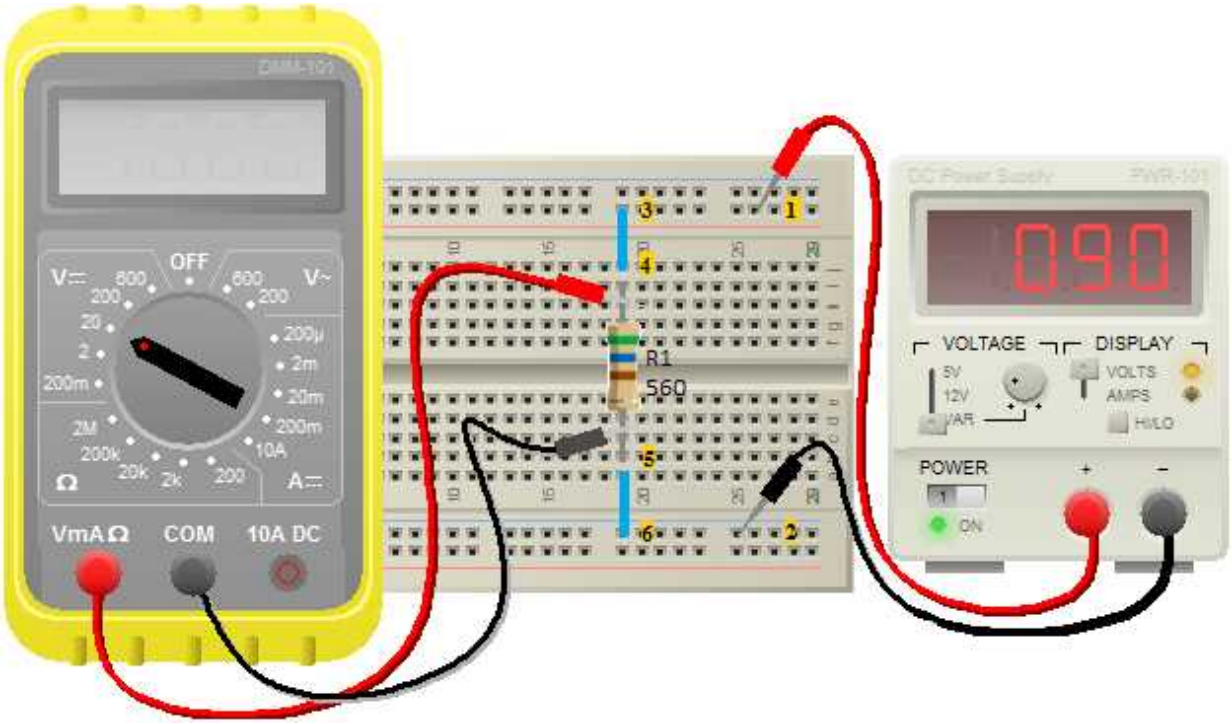


Figure 4-7: Use of multimeter to measure voltage across a circuit component.

The above procedure is almost similar to the previous one on cell voltage measuring since the meter reading is the battery voltage but for this experiment, you are requested to measure the voltage drop although the elements made up the circuit as described in the figure 4-8.

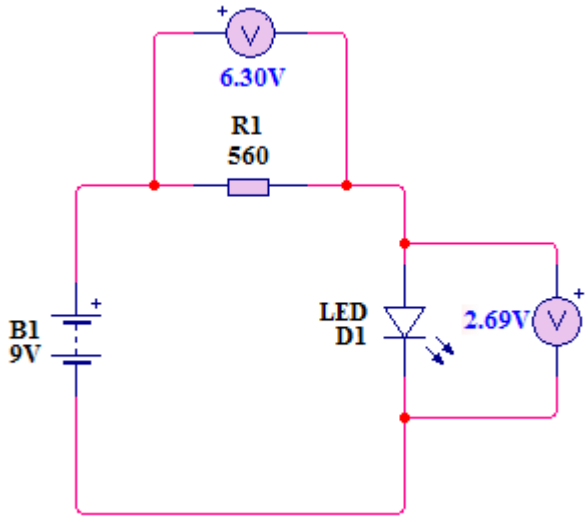


Figure 4-8: Measuring Voltage in a circuit containing two components

Hands on tip

All opposite charges (positive and negative) possess a certain potential energy because of separation between them. The difference in potential energy of the charges is potential difference or VOLTAGE. Voltage is driving force in electrical circuits and is what establishes current.

4. With the circuit closed and the LED "ON," measure the voltage across the resistor by touching the probes to the metal wires on either side of the resistor (at positions "2" and "3" in circuit arrangement of figure 4-9).
5. Measure the voltage across the LED (positions "4" and "5" in circuit arrangement of figure 4-9).

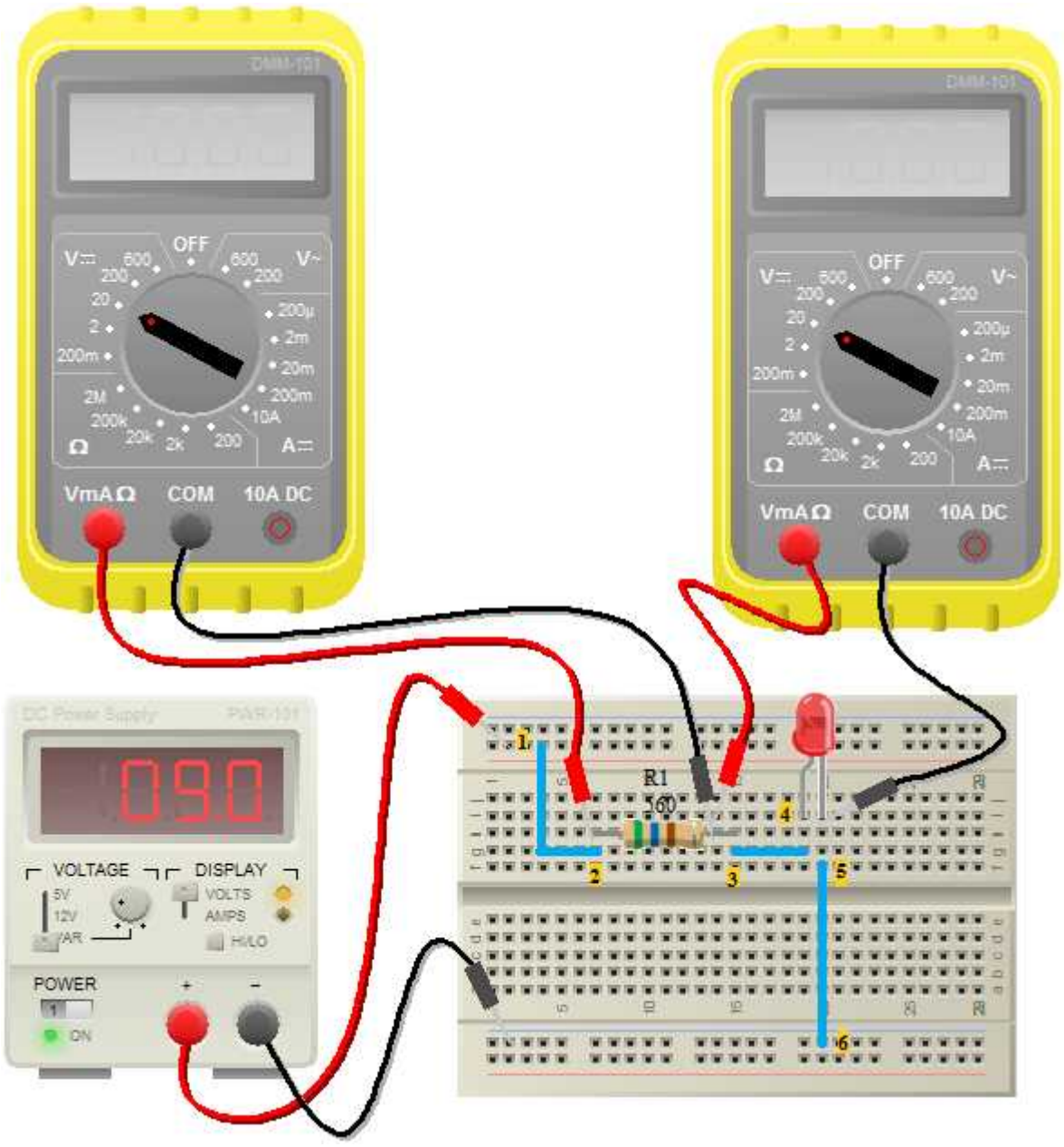


Figure 4-9: Measuring Voltage in a circuit with two components circuit connection

Current flows from the positive terminal (1), through the resistor (2 and 3), the LED (4 and 5), the jumper wire (5-6) which is directly connected to the negative terminal of the DC supply.

6. Compare the voltage of the battery to the sum of the voltage drops across the resistor and

the LED. It is possible that you can get the summation of voltage drop a little bit less than the battery's voltage (9Volt) such as 8.8Volt, with such value drift, do not panic this is practice. This is caused by imperfection of materials.

4. 1. 4. Ammeter

Ammeter is an electronic test meter used to measure the current. The ammeter has a very low internal resistance. For that reason, it requires to be connected in series within the circuit otherwise it can be destroyed. Care has to be taken when measuring high current circuits. There are the general procedures to be followed while using the Amps Function of multimeter to Measure Amperes.

General procedures:

1. Current is always measured in series with the circuit
2. Determine if it is an AC or a DC voltage to measure.
3. Set the meter to the highest AC or DC Amp range supported. If the circuit to be tested is AC but the meter will only measure the DC amps (or vice-versa), you have to leave it. The meter must be able to measure the same mode (AC or DC) amps as the voltage in the circuit, otherwise it will indicate 0.

Hands on tip

The movement of the free electrons from the negative end of a material to the positive end is the electrical current, symbolized by I. Electrical current is the rate of flow of charge. Current in a conductive material is measured by the number of electrons (amount of charge) that flow past a point in a unit of time.

I=Q/t

Where: *I*= Current in amperes (A)

Q= The charge of the electrons in coulombs (C)

t= Time in second (s)

Be aware that most multimeters will only measure extremely small amount of current, in the uA and mA ranges. 1 uA is equivalent to 0.000001 amp and 1 mA is to 0.001 amp. These are values of current that flow only in the most delicate electronic circuits, and are literally thousands (and even millions) of times smaller than values seen in the home and automotive circuits that most homeowners would be interested testing. Just for reference, a typical 100W / 220V light bulb will draw 0.4545 Amps. This amount of current would likely damage the meter beyond repair.

Figure 4-10: Analogue ammeter zeroed

4. **Use a "clamp-on" ammeter**.

a. A "clamp-on" type ammeter would be ideal for the typical homeowner requirements, and does not require opening the circuit to take measurements (figure 4-11).

If this meter were to be used to measure current through a 4700 ohm resistor across 9 Volts DC, it would be done as outlined below:

b. Insert the black probe into the "COM" or "-"jack.

c. Insert the red probe into the "A" jack.

d. Shut off power to the circuit.

e. Open the portion of the circuit that is to be tested (one lead or the other of the resistor). Insert the meter in series with the circuit such that it completes the circuit. An ammeter is placed in series with the circuit to measure current. It cannot be placed "across" the circuit the way a voltmeter is used (otherwise the meter will probably be damaged). Polarity must be observed. Current flows from the positive side to the negative side. Set the range of current to the highest value.

f. Apply power and adjust range of meter downward to allow accurate reading of pointer on the dial. Do not exceed the range of the meter, otherwise it may be damaged. A reading of about 2 milliamps should be indicated since from Ohm's law $I = V / R = (9 \text{ volts}) / (4700\ \Omega) = .00191 \text{ amps} = 1.91 \text{ mA}$.

Figure 4-11: Clamp-on multimeter

Hands on tip

When reading the scales on an analog meter, always view the scale and "needle" directly from the front and not from an angle. This practice will avoid parallax, which is an apparent change in position of the needle relative to the meter scale and results in inaccurate readings.

5. If you are measuring the current consumed by the device itself, be aware of any filter capacitors or any element that requires an inrush (surge) current when switched on. Even if the operating current is low and within the range of the meter fuse, the surge can be many times higher than the operating current (as the empty filter capacitors are almost like a short circuit). Blowing the meter fuse is almost certain if the device under test's inrush current is many times higher than the fuses rating. In any case, always use the higher range measurement protected by the higher fuse rating (if your meter has two fuses), and just be careful.

Experiment 4-3: Measuring electrical Current

Current is always measured in series within the circuit as opposed to parallel voltage measuring.

Part list

No	Items	Specifications	Quantity
1	Ammeter	Digital multimeter	1
2	Resistor	100Ω resistor	1
3	LED	Light emitting diode (yellow)	1
4	Wire	22-gauge (0.33mm^2)solid wire	40cm
5	Breadboard	Prototyping board (mini board)	1
6	Battery	3V dc supply or (2x1.5V cell)	1

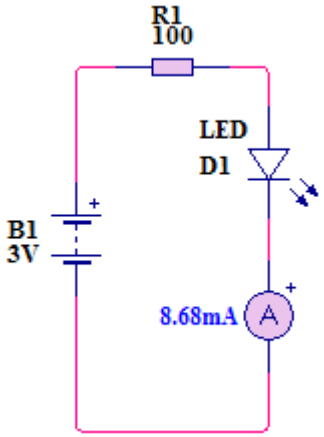


Figure 4-12: Measuring current in a circuit

Current measuring steps

1. Set the multimeter to read "direct current (DC)." Important: Check your multimeter to see where the probe should be plugged in so it reads "current."
2. In order to measure current, you have to open up the circuit and attach the leads from the multimeter so that the current flows through the multimeter. To do this, use jumper wires and wires with alligator clips to add the multimeter to the circuit, as shown in Figure 4-13.
3. The yellow wire is unplugged from the breadboard and attached to the red probe from the multimeter (6).

4. A jumper wire in black (8-9) is connected to the negative bus.
5. The other end of the wire is attached to the negative lead from the multimeter (7).
6. The current now flows from the positive terminal of the battery (1) through the resistor (2-3), the LED (4-5), the multimeter (6-7), and then to the negative terminal of the battery. 7,8 and 9 are connected together.
7. Depending on your resistor and LED, the current will be measured at around 8.68 mA (milliamps).
8. Remove LED and connect the red probe of multimeter directly to the resistor (3-4), at this time the meter reading will be almost 30 mA despite the influence of the ammeter internal resistance.

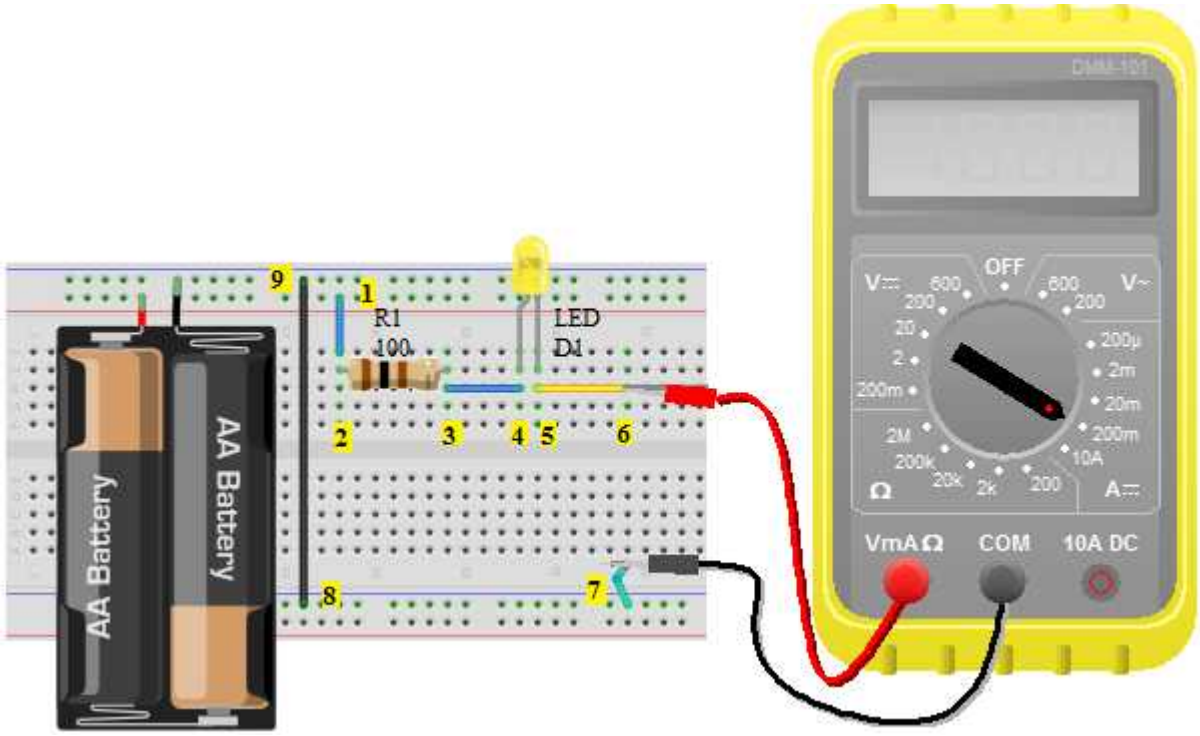


Figure 4-13: Measuring current in a circuit, real world circuit connection

Hands on tip

When measuring the current, open the circuit either between the load and the positive terminal or between the load and negative terminal of the source. Install the ammeter in the current path with respect to the polarity (negative to negative and positive to positive).

4. 1. 5. Ohmmeter

Ohmmeter is an electronics instrument used to measure electrical resistance. The property that allows material to oppose to the flow of current is called resistance while the specific device for

such task is called resistor. The ohmmeter quantifies how much a resistor restricts the follow of current in a given circuit. Here below describes the use of ohm's function to measure resistance.

General procedure:

1. Turn the multimeter on if it has a separate power switch and set to Ohm's range marked with "Ω" symbol.
   Understand that resistance and continuity are opposite. When multimeter measures resistance in ohms, it cannot measure continuity. When there is little resistance there is a great deal of continuity. Conversely, when there is a great deal of resistance, there is little continuity. With this in mind, when we measure resistance we can make assumptions about continuity based on the resistance values measured.
   - Observe the meter indication. If the test leads are not in contact with anything, the needle or pointer of an analog meter will be resting at the left-most position. This represents an infinite amount of resistance, or an "open circuit"; it is also safe to say there is the no continuity, or path between the black and red probes.
   - Careful inspection of the dial should reveal the Ohm scale. It is usually the top-most scale and has values that are highest on the left of the dial ("∞" or a sideways "8" for infinity) and gradually reduce to 0 on the right. This is opposite of the other scales; they have the lowest values on the left and increase going right.
2. Connect the black test lead to the jack marked "Common" or "-".
3. Connect the red test lead to the jack marked with the Omega (Ohm symbol) or letter "R" near it.
4. Set the range (if provided) to R x 100.
5. Hold the probes at the end of the test leads together. The meter pointer should move fully to the right. Locate the "Zero Adjust" knob and rotate so that the meter indicates "0" (or as close to "0" as possible). Note that this position is the "short circuit" or "zero ohms" indication for this R x 1 range of this meter.
   - Always remember to set to zero the analog multimeter immediately after changing resistance ranges.
6. Replace batteries (if needed). If you are unable to obtain a zero ohm indication, this may mean the batteries are weak and should be replaced. Retry the zeroing step above again with fresh batteries.
7. Measure resistance of something like a light bulb you know is good. Locate the two electrical contact points of the bulb. They will be the threaded base and the center of the bottom of the base. Have a helper hold the bulb by the glass only. Press the black probe against the threaded base and the red probe against the center tab on the bottom of the base. Watch the needle move from resting at the left and move quickly to 0 on the right. Digital multimeter displays numerically the resistance of the device under measuring.
8. Try different ranges. Change the range of the meter to R x 1. Zero the meter again for this range. Repeat the step above. Observe how the meter did not go as far to the right as before. The scale of resistance has been changed so that each number on the R scale can be read directly. In the previous step, each number represented a value that was 100 times greater. Thus, 150 really was 15,000 before. Now, 150 is just 150. Had the R x 10 scale been se-

lected, 150 would have been 1,500 for example. The scale selected is very important for accurate measurements. With this understanding, study the R scale. It is not linear like the other scales. Values at the left side are harder to accurately read than those on the right. Trying to read 5 ohms on the meter while in the R x 100 range would look like 0. It would be much easier at the R x 1 scale instead. This is why when you are testing resistance, adjust the range so that the readings may be taken from the middle rather than the extreme left or right sides.

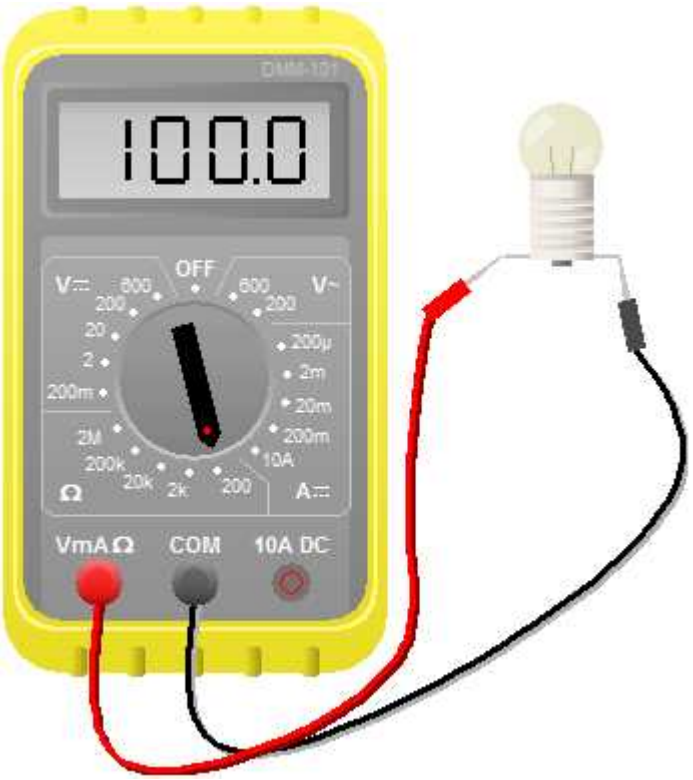


Figure 4-14: Measuring resistance of a bulb using Ohmmeter

9. Test resistance between hands. Set the meter to the highest R x value possible. Zero the meter.
    - Loosely hold a probe in each hand and read the meter. Squeeze both probes tightly. Notice the resistance is reduced.
    - Free the probes and wet your hands. Hold the probes again. Notice that the resistance is lower still.
    - For these reasons, it is very important that the probes not touch anything other than the device under test. A device that has burned out will not show "open" on the meter when testing if your fingers provide an alternate path around the device, like when they are touching the probes. Testing round cartridge type and older style glass automotive fuses will indicate low values of resistance if the fuse is lying on a metal surface when under test. The meter indicates the resistance of the metal surface that the fuse is resting upon (providing an alternate path between the red and black probe around the fuse) instead of trying to determine resistance through the fuse. Every fuse, good or bad, will indicate "good".

4. 2. Oscilloscope

Oscilloscope is an electronic test instrument for measuring and observing of constantly varying signal voltages. The oscilloscope is basically a graph-displaying device that traces a graph of measured electrical signal on its screen. In most applications the graph shows how signal change over time. The vertical axis of the display screen represents voltage and the horizontal axis represents time. You can measure amplitude, period, and frequency of a signal using oscilloscope. Also, you can determine the pulse width, duty cycle, rise time and fall time of a pulse waveform. Most oscilloscopes can display at least two signals on the screen at one time, enabling you to observe their time relationship. A front panel of a typical commercial oscilloscope is shown in figure 4-15.

4. 2. 1. Oscilloscope user's manuel guide

Each mark of oscilloscope comes with user's manual to guide for manipulating. Most of oscilloscopes have common control keys. Let describe the function of control keys of the most popular digital oscilloscope called Agilent 54622D 100 MHz.

Front panel controls keys

1. **Channel On/Off key:** Use this key to switch the channel on or off, or to access the channel's menu in the softkeys. There is one channel on/off key for each channel.
2. **Math key:** The math key provides access to FFT (Fast Fourier Transform), multiply, subtract, differentiate, and integrate functions.
3. **Display:** The display shows captured waveforms using a different color for each channel.
4. **Vertical sensitivity control:** Also called VOLTS/DIV control. Vertical attenuation for channel provides step adjustment of vertical sensitivity. Use this knob to change the vertical sensitivity (gain) of the channel.
5. **Autoscale Key:** When you press the autoscale key the oscilloscope will quickly determine which channels have activity, and it will turn these channels on and scale them to display the input signals.
6. **Entry knob:** The entry knob is used to select items from menus and to change values. Its function changes based upon which menu is displayed. Note that the curved arrow symbol ↻ above the entry knob illuminates whenever the entry knob can be used to select a value. Use the entry knob to select among the choices that are shown on the softkeys.
7. **Horizontal Sweep Speed control:** Also called Time base, TIME/DIV control, provides steps selection of sweep rate for the main time base. This control has 23 steps from 0.1uS time/div to 2S time/div in 1-2-5 sequences. Turn this control to adjust the sweep speed. This changes the time per horizontal division on the display. When adjusted after the waveform has been aquired and the oscilloscope is stopped, this has the effect of stretching out or squeezing the waveform horizontally.
8. **Horizontal Main/Delayed key:** Press this key to access the menu where you can split the oscilloscope display into Main and Delayed sections, and where you can select XY and roll modes. You can also select horizontal time/division vernier and

select the trigger time reference point on this menu.

9. **Horizontal Delay Control:** when the oscilloscope is running, this control lets you set the acquisition window relative to the trigger point. When the oscilloscope is stopped, you can turn this knob to pan through the data horizontally. This lets you see the captured waveform before he trigger (turn the knob clockwise) or after the trigger (turn the knob counterclockwise).
10. **Measure key:** Press the cursors key to switch on cursors that you can use for making measurements. Press the "

" key to access a set of predefined measurements.
11. **Waveform key:** The acquire key lets you set the oscilloscope to acquire in Normal, Peak Detect, Averaging, or High Resolution modes, and lets you turn Realtime sampling off or on. The display key lets you access the menu where you can select infinity persistence, switch vectors on or off, and adjust the display grid (graticule) intensity
12. **Run controls:** Press the "

" key to make the oscilloscope begin looking for a trigger. The Run/Stop key will illuminate in green. If the trigger mode is set to "Normal", the display will not update until a trigger is found. If the trigger mode is set to "Auto", the oscilloscope looks for a trigger, and if none is found, it will automatically trigger, and the display will immediately show the input signals. In this case, the background of the Auto indicator at the top of the display will flash, indicating that the oscilloscope is forcing triggers.

    Press "

" again to stop acquisition of data. The key will illuminate in Red.

    Now you can pan across and zoom-in on the acquires data.

    Press "

" key to make a single acquisition of data. The key will illuminate in yellow untill oscilloscope triggers.
13. **Digital channel controls:** These controls switch the digital channels on/off, and can be used to select a digital channel for repositioning on the display.
14. **Trigger controls:** These controls determine how the oscilloscope triggers to capture data.
15. **Trigger input:** Use this input for external trigger input.
16. **Utility key:** Press this key to access the utility menu, which lets you configure the oscilloscope's I/O settings, printer configuration, file explorer, service menu, and other options.
17. **File key:** Press file key the key to access the file functions such as save or recall a waveform or setup. Or press the quick print key to print the waveform from display.
18. **Vertical Position control:** Use this knob to change the channel's vertical position on the display. There is one vertical position control for each channel.
19. **Channel Input BNC connector:** Attach the oscilloscope probe or BNC cable to the BNC connector. This is the channel's input connector.
20. **Power switch:** Press once to switch power ON; press again to power OFF.

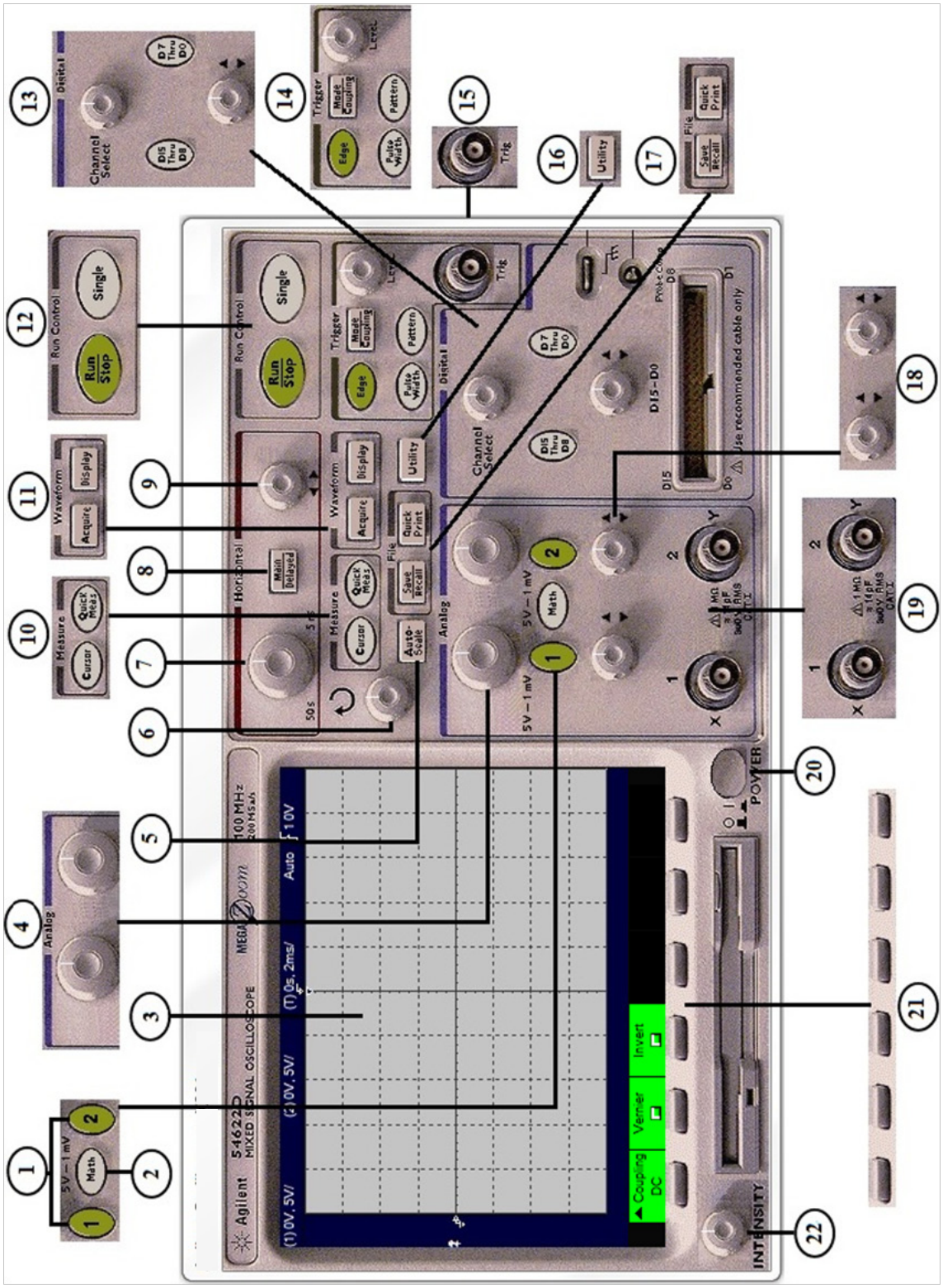
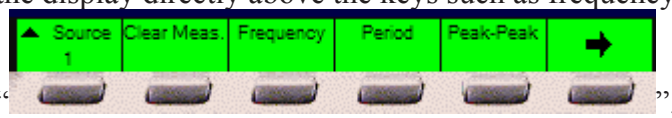


Figure 4-15: Oscilloscope front pannel control keys

chap 4

21. **Softkeys:** The functions of these keys change based upon the menus shows on the display directly above the keys such as frequency and voltage measuring



".

22. **Intensity control:** Rotate clockwise to increase analog waveform intensity; counterclockwise to decrease analog waveform intensity. You can vary the intensity control to bring out signal detail, much like an analog oscilloscope. Digital channel waveform intensity is not adjustable.

4. 2. 2. Interpreting the display

1. Analog channels and ground levels
2. Analog channel one (CH1)
3. Analog channel one (CH1) vertical sensitivity or CH1 voltage/Division
4. Analog channel two (CH2)

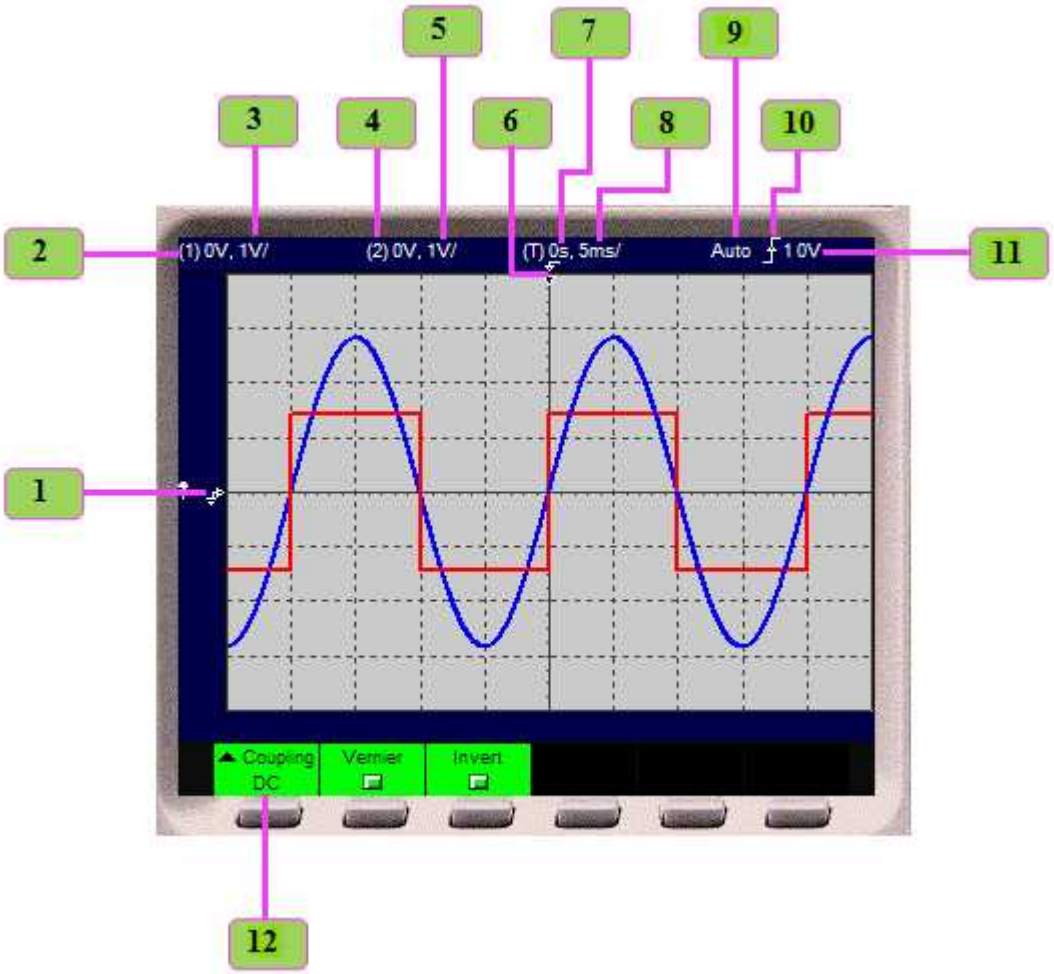


Figure 4-16: Agilent oscilloscope 54622D 100MHz display

5. Analog channel two (CH2) vertical sensitivity or CH2 voltage/Division
6. Trigger point time reference
7. Delay time
8. Sweep speed or horizontal sensitivity
9. Run/Stop and automatic mode
10. Trigger type
11. Trigger level or Digital threshold
12. AC/DC coupling mode

Experiment 4-4: Oscilloscope calibration

An oscilloscope is an electronic measuring instrument and helps to visualize the shape of the signal. Before taking a measurement, verify the settings of some key controls on oscilloscope. The exact steps to follow to set up the oscilloscope vary depending on the exact type and model of oscilloscope, so better to read the instruction manual that came with the oscilloscope. But the general steps should be as follows:

1. Examine all the controls of the oscilloscope and set them to normal positions.

   For most oscilloscopes, all rotating dials should be centered, all pushbuttons should be out, and all slide switches and paddle switches should be up.

2. Turn on oscilloscope.

   If it is an old-fashioned CRT kind, give it a minute or two to warm up.

3. Set the VOLTS/DIV control to 1.

   This sets the scope to display one volt per vertical division. Depending on the signal you want to be displayed, you may need to increase or decrease this setting, but one volt is a good starting point.

4. Set the TIME/DIV control to 1.

   This control determines the time interval represented by each horizontal division on the display. Try turning this dial to its slowest setting. Then, turn the dial one notch at a time and watch the dot speed up until it becomes a solid line.

5. Set the Trigger switch to Auto.

   The Auto position enables the oscilloscope to stabilize the trace on a common trigger point in the waveform. If the trigger mode is not set to Auto, the waveform may drift across the screen, making it difficult to watch.

6. Connect a probe to the input connector.

   If the oscilloscope has more than one input connector, connect the probe to the one labeled *A* or CH1.

   Oscilloscope probes include a probe point, which you connect to the input signal and a separate ground lead. The ground lead usually has an alligator clip. When testing a circuit, this clip can be connected to any common ground point within the circuit. In some probes, the ground lead is detachable, so you can remove it when it is not needed.

7. Touch the end of the probe to the oscilloscope calibration terminal.

   This terminal provides a sample square wave that you can use to calibrate the oscilloscope's display. Some oscilloscopes have two calibration terminals, labeled and. If the oscilloscope has two terminals, touch the probe to the 2 V terminals.

   For calibrating, it is best to use an alligator clip test probe. If your test probe has a pointy tip instead of an alligator clip, you can usually push the tip through the little hole in the end of the calibration terminal to hold the probe in place.

   It is not necessary to connect the ground lead of your test probe for calibration.

8. If necessary, adjust the TIME/DIV and VOLTS/DIV controls until the square wave fits nicely within the display.
9. If necessary, adjust the Y-POS control to center the trace vertically.
10. If necessary, adjust the X-POS control to center the trace horizontally.
11. If necessary, adjust the Intensity and Focus settings to get a clear trace.

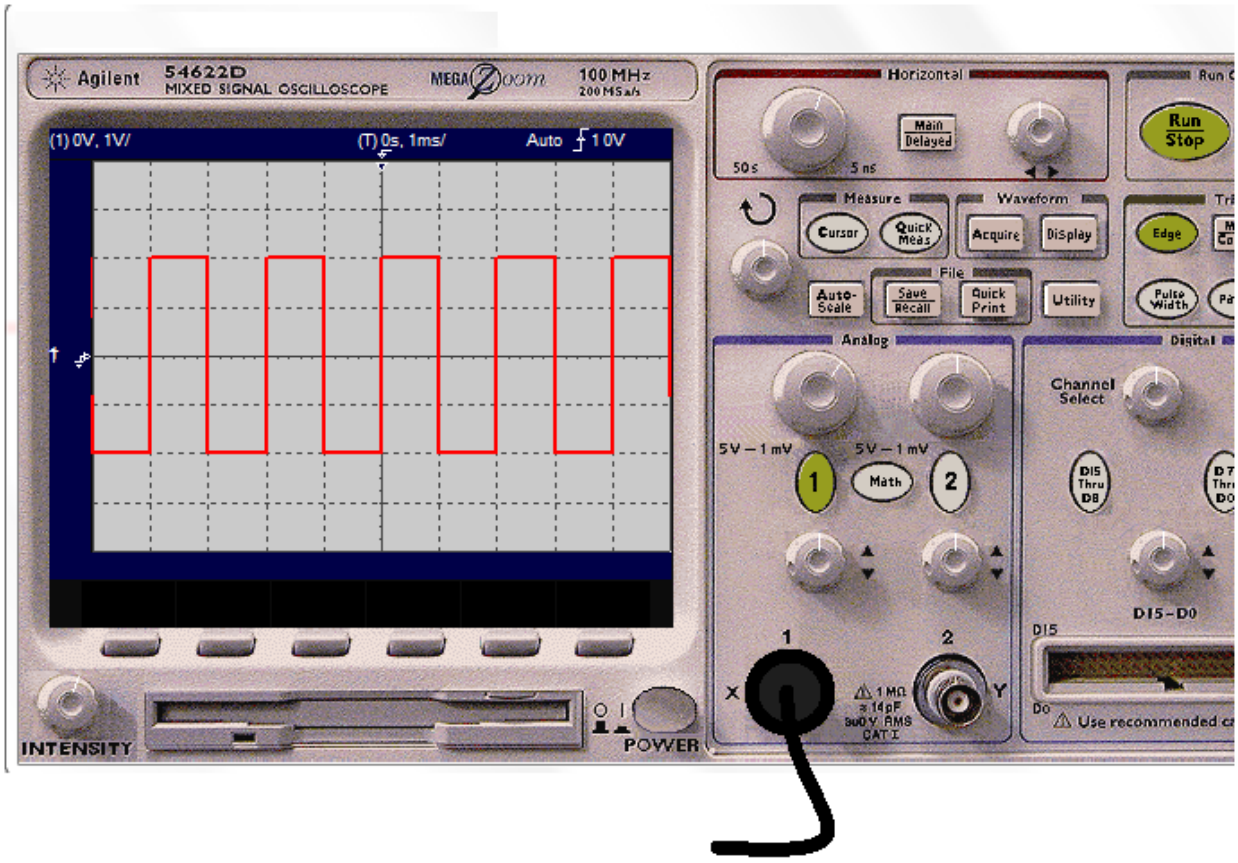


Figure 4-17: Oscilloscope displaying a square wave

With all these procedures, you are now ready to begin viewing the waveforms of actual electronic signals.

Experiment 4-5: Measuring Direct Current with oscilloscope

One important function of the oscilloscope is to make voltage measurements. The oscilloscope is

capable of measuring both AC and DC. Now measure the voltage of series cell batteries by using oscilloscope.

Part list

No	Items	Specifications	Quantity
1	Oscilloscope	Digital oscilloscope	1
2	3V DC supply	1.5V AA cell Battery	2

Procedure

1. Switch on the oscilloscope
2. Adjust voltage/Division to 1V
3. Hold oscilloscope's probe against battery's polarity; red probe on positive terminal and black probe on negative terminal of the battery

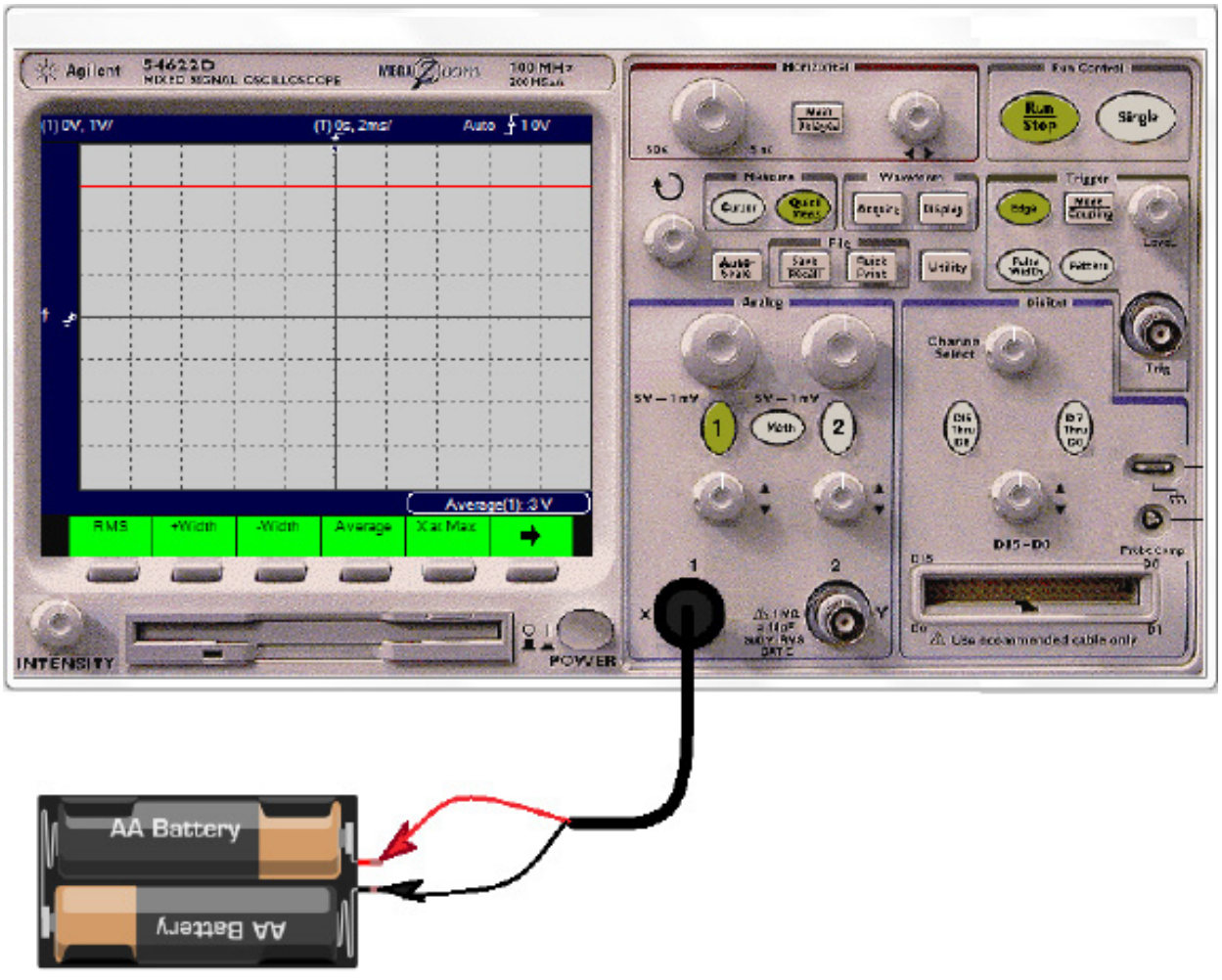


Figure 4-18: Measuring DC voltage using oscilloscope

4. Measure voltage using quick meas of the oscilloscope or calculate by using formula. Consider: - Vol/Division =1V;

   - Number of division =3

   Thus, V = Volt/Div* Number of division

   =1V/Div*3Div =3V

Experiment 4-6: Measuring Alternating current quantities using oscilloscope

The oscilloscope is capable of measuring AC components such as frequency, period and maximum voltage value. This experiment will demonstrate the way the oscilloscope is used to measure the above mentioned quantities.

Part list

No	Items	Specifications	Quantity
1	Oscilloscope	Digital oscilloscope	1
2	AC supply	Agilent function generator	1

Procedure

1. Turn on both function generator and oscilloscope
2. Set function generator to produce 2.121V rms value at 50Hz
3. Adjust oscilloscope to 1V/division and time base at 5mSec/Division
4. Connect the output of the function generator to CH1 of the oscilloscope by respecting the polarities (red lead of the function generator to red probe of the oscilloscope and black lead of the function generator to black probe of the oscilloscope.
5. Use oscilloscope's quick meas to measure period, frequency, maximum voltage and peak-to-peak voltage
6. If you are not using digital oscilloscope proceed with calculation demonstrated below.

Calculation of the period, frequency and voltage of an AC (alternating current) supply from an oscilloscope trace.

Period

The period of an AC supply is the time taken for one complete oscillation. You can find this by looking at the time between one peak and the next, between one through and the next, or between any two identical places on adjacent oscillations.

In the oscilloscope trace on this page, one horizontal division represents 5 ms (five milliseconds). There are four divisions between two adjacent peaks, so the period is:

$$T = 4 \times 5 = 20 \text{ ms}$$

Frequency

The frequency of an AC supply is the number of oscillations per second. You can find it from the period:

- Frequency = 1/T
- Remember to convert to seconds if needed. In this example,

  $20\ ms = 20*10^{-3}\ Sec = 20/1000\ Sec = 0.020\ Sec.$
- Frequency = 1/(0.020 Sec) = 50 Hz
- In most of the countries, the main frequency is 50 Hz or 60 Hz but you may get other frequencies (and periods) to calculate in the examination.

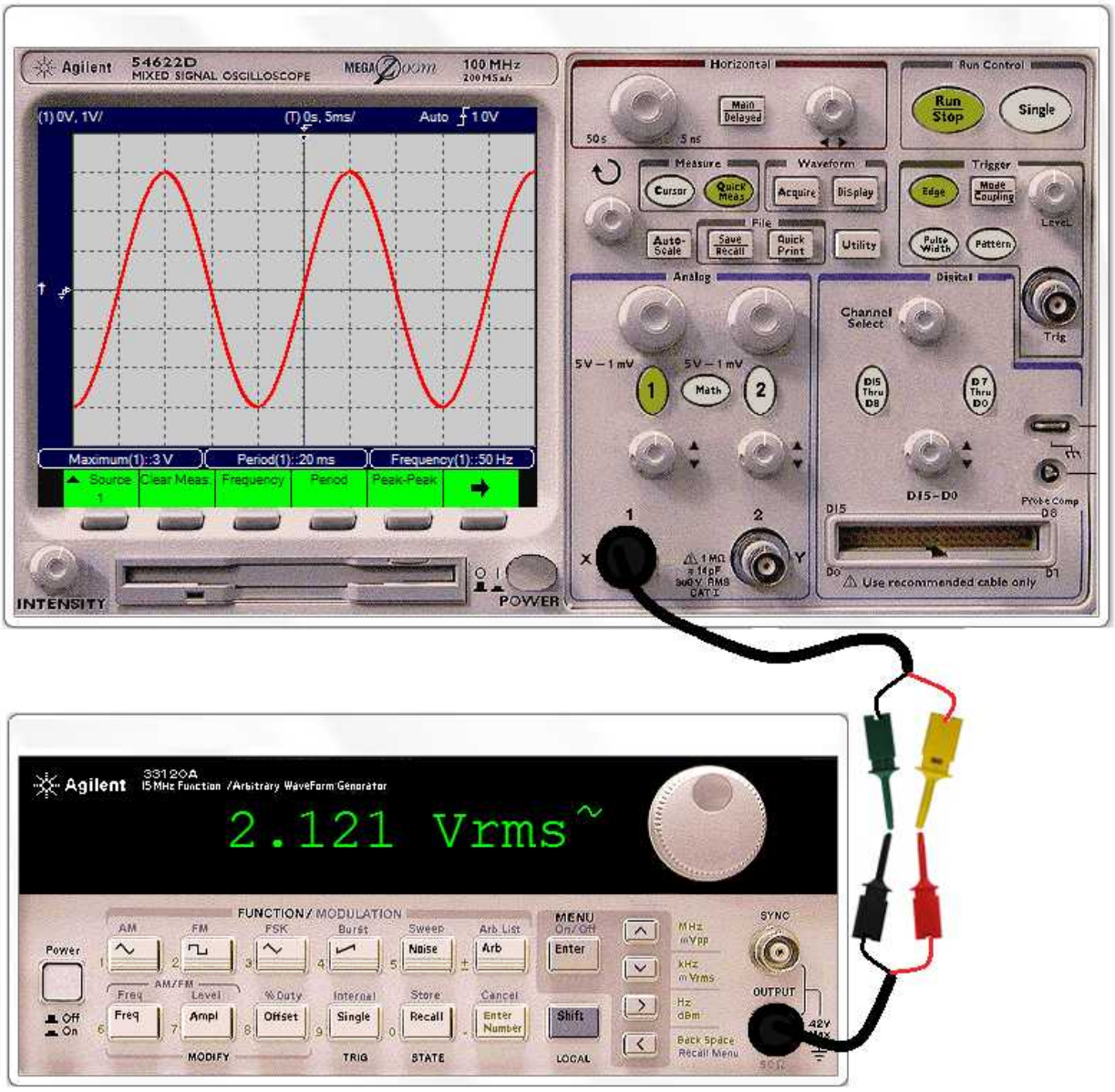


Figure 4-19: Measuring sinewave quantities using oscilloscope

Voltage

Voltage is determined by using vertical sensitivity from oscilloscope display.

Each square on the oscilloscope display is called "Division"

Just as voltmeter has a range switch, so does an oscilloscope. This switch selects volts per division. For example, at 2volts/div position means that one vertical division represents two volts. By taking example given for the above experiment we have: 3divisions at 1V/division
Thus;

Peak Amplitude = (Volt/Div)*(number of division)
= (1Volt/Div)*(3Div)
= 3V

Peak to Peak amplitude = Peak amplitude*2 = 3V*2 = 6V

Conversions of sine wave values summary

To change from	To	Multiply by
Peak	rms	0.707
Peak	Peak-to-peak	2
Peak	Average	0.637
rms	Peak	1.414
Peak-to-peak	Peak	0.5
Average	Peak	1.57

Table 4-1: Summary of sine wave values conversions

The digital scope is more widely used than analog scope. However, this type can be used in many applications; each has characteristics that make it more suitable for certain situations. Analog scope displays waveforms as they occur in "real time." Digital scopes are useful for measuring transient pulses that may randomly or only once. Also, because information about measured waveform can be stored in a digital scope, it may be viewed at some later time, printed out, or thoroughly analyzed by a computer or other means.

Basic operation of Analog Oscilloscope: To measure a voltage, a probe must be connected from the scope to point in a circuit at which the voltage is present. Generally, a x10 probe is used to reduce (attenuate) the signal amplitude by ten. The signal goes through the probe into the vertical circuits where it is either further attenuated (reduced) or amplified depending on the actual amplitude and on where you set the vertical control of the scope. The vertical circuits then drive the vertical deflection plates of the CRT (cathode ray tube). Also, the signal goes to the trigger circuits that trigger the horizontal circuits to initiate repetitive horizontal sweeps of the electron beam across the screen using a sawtooth waveform. There are many sweeps per second so that the beam appears to form a solid line across the screen in the shape of the waveform.

Basic operation of Digital Oscilloscope: Some parts of a digital scope are similar to the analog scope. However, the digital scope is more complex than analog scope and typically has an LCD (Liquid Crystal Display) screen rather than CRT. Rather than displaying a waveform as it occurs, the digital scope first acquires the measured analog waveform and converts it to a digital processed. The data then goes to the reconstruction and display circuits for displaying in its original analog form.

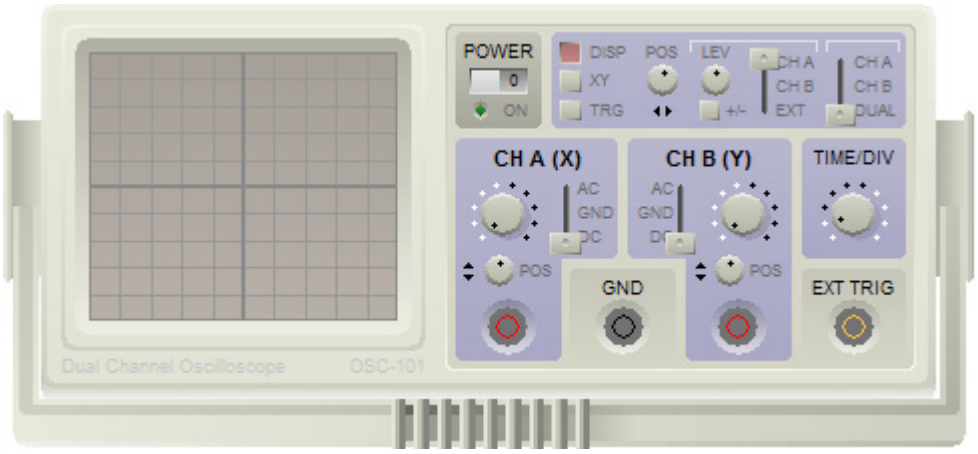
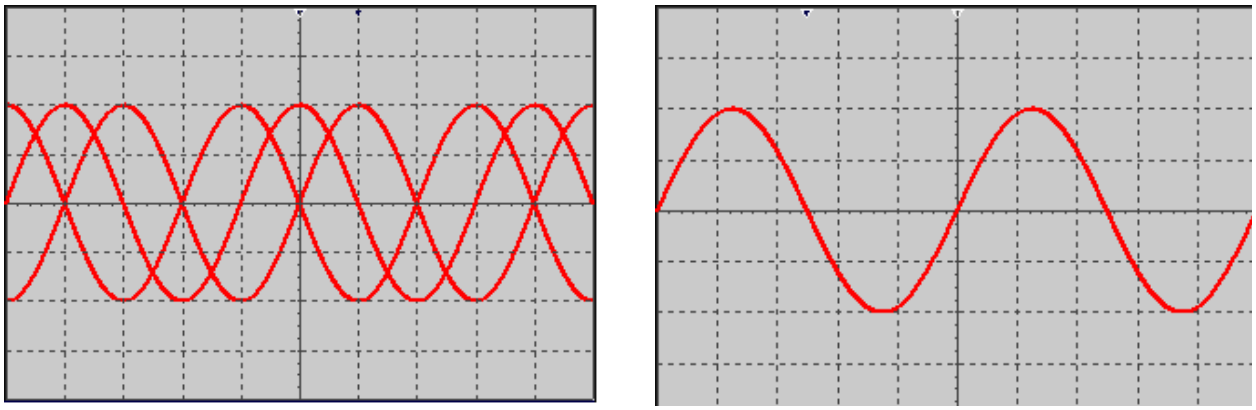


Figure 4-20: Typical analog oscilloscope

Triggering the waveform

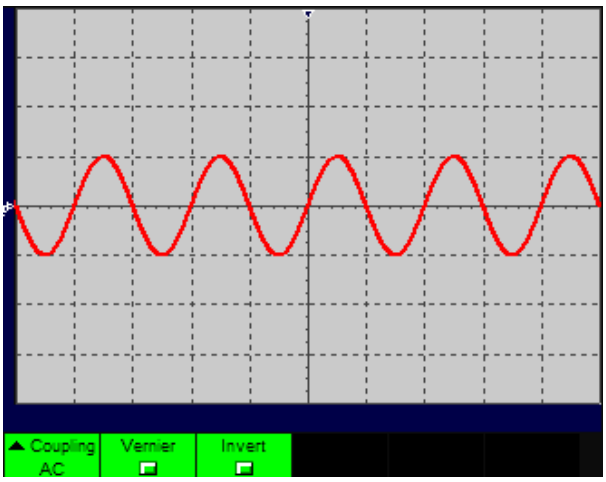
Triggering stabilizes a waveform on the screen and properly triggers on a pulse that occurs only on time or randomly. Also it allows to observe time delays between two waveforms. Figure 4-21 compares a trigger to an untriggered signal. The untriggered signal tends to drift across the screen producing what appears to be multiple waveforms.



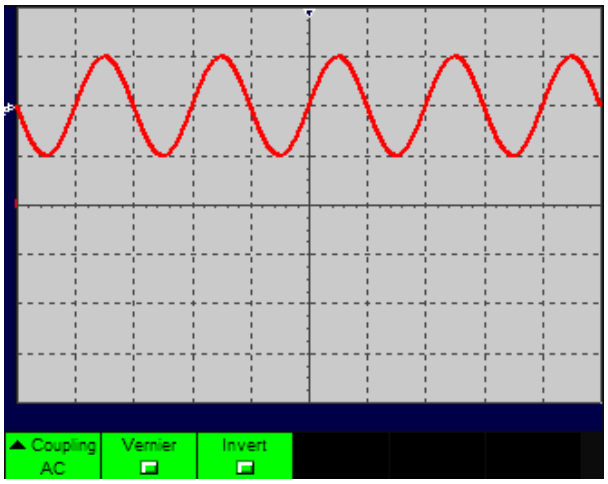
(1) **(2)**

Figure 4-21: Comparision of untriggered waveform (1), and triggered waveform (2)

Coupling a signal into the scope: Coupling is the method used to connect a signal voltage to be measured into the oscilloscope. The DC and AC coupling modes are selected from the vertical menu. DC coupling allows a waveform including its dc components to be displayed. AC coupling blocks the dc components of a signal so that you see the waveform centered to 0V. the ground mode allows to connect the channel input to ground to see where the 0V reference is on the screen. Figure 4-22 illustrates the result of DC and AC coupling using a sinusoidal waveform that has a dc component.



(1)



(2)

Figure 4-22: AC coupled waveform (1), DC coupled waveform containing dc component(2)

Things to remember:

There are a variety of oscilloscope model and the controls of every oscilloscope model are unique. Even if many alike control keys have the same working principle, be sure to read the owner's manual that came with your oscilloscope to see if there are any other setup or calibration procedures you need to follow before feeding real signals into your oscilloscope.

Before connecting the probes to the circuit, you sould align the two horizontal lines (traces) so that they appear as a single line across the center of the scope screen. To do so, ground the probe tips and adjust the vertical position knobs to move the traces toward the center line of the screen until they are superimposed. This procedure ensures that both wave-forms have the same zero acrossing so that an accurate phase measurement can be made.

Hands on tip

Since all instruments tend to affect the circuit being measured due to loading, most oscilloscope probes proved an attenuation network to minimize loading effects. Probes that attenuate the measured signal by a factor of 10 are called x10 (times ten) probes. Probes with no attenuation are called x1 (times one) probes. The oscilloscope adjusts its calibration for the attenuation of the type of probe being used. For most measurements, the x10 probe should be used. However, if you are measuring very small signal, x1 may be the best choice. The probe has an adjustment that allows you to compensate for the input capacitance of the oscilloscope. Most oscilloscopes have a probe compensation output that provides a calibrated square wave for probes compensation. Before making measurement, you should make sure that the probe is properly compensated to eliminate any distortion introduced.

Chapter five

Electronic Passive Components

Objectives

When you have studied this chapter, you should

- Identify electronic passive component values using color code
- Be familiar with capacitor and its ability to store electrical charges
- Have an understanding of charging and discharging process which occur in circuits containing capacitors
- Diagnosis fault and replacement to the equivalent component
- Recognize series and parallel connected loads
- Have an understanding that series-connected loads all pass the same current
- Have an understanding that parallel-connected load all share the same applied voltage
- Be familiar with Kirchhoff's laws
- Be capable of analyzing relatively simple circuits and networks containing series and parallel-connected loads

Further reading
Study aids for this chapter are available at
• www.electronics-tutorials.ws
• James H. Harter, Paul Y. Lin, *Essentials of electric circuits*, pp. 96–97

Components that are specifically designed to have a certain amount of resistance are called *resistors*. The principle applications of resistors are to limit the current, divider voltage, and, in circuit case, generate heat. Although different types of resistors come in many shapes and sizes, they can be placed in one of two main categories: *fixed* and *variable*.

A passive electrical component that stores electrical charge and has property of capacitance is called *capacitor*. A capacitor is made of two parallel conductive plates separated by an insulating material called the dielectric. Connecting leads are attached to the parallel plates.

A passive electrical component formed by a coil of wire and which exhibits the property of inductance is called *inductor*.

In this chapter we are going to describe these three electrical passive components

5. 1. Resistor

A resistor is a passive two-terminal electronics component that restricts the flow of current in electrical or electronic circuit. Resistors are the most commonly used component in electronics and their function is to create specified values of current and voltage in a circuit.

(1) (2)

Figure 5-1: Resistor American symbol (1), Resistor European symbol (2)

5. 1. 1. The unit of resistance

The unit for measuring resistance is the OHM. (The Greek letter Ω - called Omega). Higher resistance values are represented by "k" (kilo-ohms) and M (Meg ohms). For example, 560 000 Ω is represented as 560k, while 5 600 000 Ω is represented as 5M6. The dot is generally omitted as it can easily be lost in the printing process. In some circuit diagrams, a value such as 4 or 270 represents a resistance in ohms. Another common practice is to use the letter E for resistance in ohms. The letter R can also be used. For example, 270E (270R) stands for 270 Ω, 2E7 stands for 2R7.

5. 1. 2. Identifying resistor value

The value of a resistor can be identified by either using Ohmmeter or by using color code.

Resistor marking

Most axial resistors use a pattern of colored stripes to indicate resistance. Surface-mount resistors are marked numerically, if they are big enough to permit marking; more-recent small sizes are impractical to mark. Cases are usually tan, brown, blue, or green, though other colors are occasionally found such as dark red or dark gray.

Identifying Resistor Value by using Color Dode

Most composition resistors have their ohmic value indicated by a series of colored bands around the body of the unit. The colors used are those designated by the Electronic Industries Association (E.I.A.), and have been universally adopted. In practice it is better to be familiar with these codes.

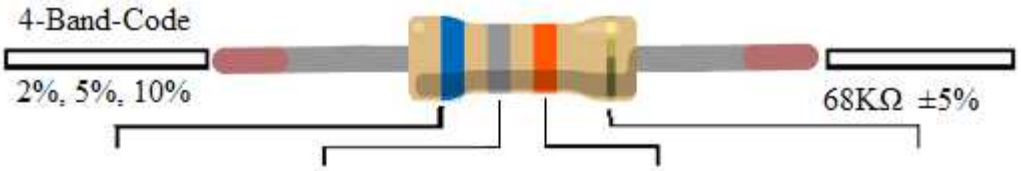
Some types of fixed resistors with value tolerance of 5% or 10% are color coded with four bands to indicate the resistance value and the tolerance. Certain precision resistors with tolerances of 2%, 1%, or less are generally color coded with five bands as shown in table 5. The bands are always located closer to the end.

The 4-band color code is read as follow:

1. Start with the band closest to one end of the resistor. The first band is the first digit of the resistance value. If it is not clear which is the band end, start from the end that does not begin with a gold or silver band.

2. The second band is the second digit of the resistance value.
3. The third band is the number of zeros following the second digit, or the multiplier.
4. The fourth band indicates the percent tolerance and is usually gold or silver. If there is no fourth band, the tolerance is ± 20%.

For example, a 5% tolerance means that the actual resistance value is within ± 5% of the color-coded value. Thus, a 100Ω with a tolerance of ± 5% can have an acceptable range of values from a minimum of 95Ω to a maximum of 105Ω. As indicated in the table, for resistor values less than 10Ω, the third band is either gold or silver. Gold in the third band represents a multiplier of 0.1, and silver represents 0.01. For example, a color code of red, violet, gold, and silver represents 2.7Ω with a tolerance of ± 10%. A table of standard resistor values is shown in table 5-2 through table 5-6.



Color	1st Band	2nd Band	3rd Band	Multiplier	Tolerance
Black	0	0	0	1Ω	
Brown	1	1	1	10Ω	± 1% (F)
Red	2	2	2	100Ω	± 2% (G)
Orange	3	3	3	1KΩ	
Yellow	4	4	4	10KΩ	
Green	5	5	5	100KΩ	±0.5% (D)
Blue	6	6	6	1MΩ	±0.25% (C)
Violet	7	7	7	10MΩ	±0.10% (B)
Grey	8	8	8		±0.05%
White	9	9	9		
Gold				0.1	± 5% (J)
Silver				0.01	± 10% (K)

Table 5-1: Resistor color codes

The 5-band color code is read as follow:

Begin at the band closest to one end,

1. The first band is the first digit of the resistance value.
2. The second band is the second digit of the resistance value.

3. The third band is the third digit of the resistance value.
4. The fourth band is the multiplier or the number of zeroes after the third digit
5. The fifth band indicates the tolerance

Example: Find the resistance in ohms and the percent tolerance for each of the color-coded resistors as shown below.

(a)

(b)

a) First band is red = 2, Second band is violet = 7, Third band is orange = 3 zeros, the fourth band is silver = ± 10% tolerance;

Thus, R = 27,000Ω ± 10% or 27KΩ ± 10%

b) First band is green = 5, Second band is blue = 6, Third band is red = 2, fourth band is black = no zeros or multiply by 1, the fifth band is brown = ± 1% tolerance;

Thus, R = 562Ω ± 1%

Some examples of color code resistors with their equivalent values.

10Ω	12Ω	15Ω	18Ω
22Ω	**27Ω**	**33Ω**	**39Ω**
47Ω	**56Ω**	**68Ω**	**82Ω**

The use of multiple of tenth for higher value is achieved by simply changing the multiplier color code.

Identifying Resistor Value by using Ohmmeter

The resistor's value is measured by using ohmmeter but care has to be taken on the gotten value since this can differ to that of color codes. The reason behind is that resistors' value vary within margin given by their corresponding tolerance, ohmmeter calibration and to the state of atmosphere such as temperature. Sometimes the value given by the ohmmeter does not conform to the resistors' standard values found on market. In the next tutorial we will give the resistor standard values corresponding to their tolerance.

Experiment 5-1: Measuring Resistance

Use digital multimeter set in Ohm's range to measure a given resistor.

Parts list

No	Items	Specifications	Quantity
1	Ohmmeter	Digital multimeter	1
2	Resistor	5.6KΩ	1

Procedure

1. Set the multimeter to the Ω range (Ohm's range)
2. Set at high mode value than what you expect to measure (10K or 20K).
3. Hold the probes against the resistor's legs.

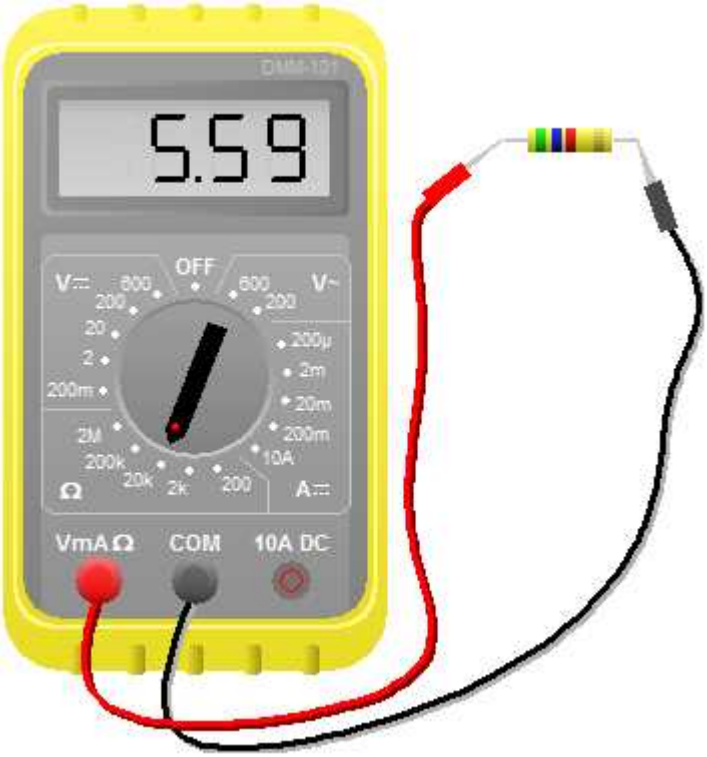


Figure 5-2: Multimeter set in Ohm's range to measure resistance

The meter will read one of three things, 0.00, "1", or the actual resistor value. If the meter reads for example 5.59, then you have got a 5.59kΩ (Kilo-Ohm) resistor. At this time you are in the 20kΩ, so you need to move the decimal three places to the right or 5590 Ohms. The expected value by using color codes was 5.6KΩ. The reasonable range to measure 5.6KΩ resistor is 10KΩ or somewhat 20KΩ. The use higher calibration can ignore the decimal values and give a wrong value. For example, the use of 2MΩ range reads 6KΩ which is erroneous. Practically 5.59KΩ resistor does not exist in resistor standard values packet and does not found on market. It is better to refer to the standard values and choose the one closest to the value gotten.

5. 1. 3. Standard Resistor Values

On market, resistors are offered in a number of standard ranges, often called "preferred values". These ranges, or series, are set out by the Electronic Industries Association (EIA), and are E3, E6, E12, E24, E48, E96 and E192. The number after the 'E' denotes the number of values the series contains per decade. The series are logarithmic and are derived from the resistor tolerance; resistors with a tighter tolerance can have more values in the series that will not overlap one another.

The underlying principle to select values for components based on the tolerances with which they are able to be manufactured is based on this theory. Using 10% tolerance devices as an example, suppose that the first preferred value is 100 ohms. It makes little sense to produce a 105 ohm resistor since 105 ohms falls within the 10% tolerance range of the 100 ohm resistor. The next reasonable value is 120 ohms because the 100 ohm resistor with a 10% tolerance is expected to have a value somewhere between 90 and 110 ohms. The 120 ohm resistor has a value ranging between 110 and 130 ohms. Following this logic, the preferred values for 10% tolerance resistors between 100 and 1,000 ohms would be 100, 120, 150, 180, 220, 270, 330, 390, 470, 560, 680 and 820.

The EIA "E" series specify the preferred values for various tolerances as follows:

E3 50% tolerance (no longer used)
E6 20% tolerance (now rarely used)
E12 10% tolerance
E24 5% tolerance
E48 2% tolerance
E96 1% tolerance
E192 0.5, 0.25, 0.1% and higher tolerances

E12 Series

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Standard resistor values (±10%) E12 Series							
1R0	10R	100R	1K0	10K	100K	1M0	10M
1R2	12R	120R	1K2	12K	120K	1M2	
1R5	15R	150R	1K5	15K	150K	1M5	
1R8	18R	180R	1K8	18K	180K	1M8	
2R2	22R	220R	2K2	22K	220K	2M2	
2R7	27R	270R	2K7	27K	270K	2M7	
3R3	33R	330R	3K3	33K	330K	3M3	
3R9	39R	390R	3K9	39K	390K	3M9	
4R7	47R	470R	4K7	47K	470K	4M7	
5R6	56R	560R	5K6	56K	560K	5M6	
6R8	68R	680R	6K8	68K	680K	6M8	
8R2	82R	820R	8K2	82K	820K	8M2	
8R2	82R	820R	8K2	82K	820K	8M2	

Table 5-2: E12 series standard resistor values

E24 Series

Standard resistor values (±5%) E24Series							
1R0	10R	100R	1K0	10K	100K	1M0	10M
1R1	11R	110R	1K1	11K	110K	1M1	
1R2	12R	120R	1K2	12K	120K	1M2	
1R3	13R	130R	1K3	13K	130K	1M3	
1R5	15R	150R	1K5	15K	150K	1M5	
1R6	16R	160R	1K6	16K	160K	1M6	
1R8	18R	180R	1K8	18K	180K	1M8	
2R0	20R	200R	2K0	20K	200K	2M0	
2R2	22R	220R	2K2	22K	220K	2M2	
2R4	24R	240R	2K4	24K	240K	2M4	
2R7	27R	270R	2K7	27K	270K	2M7	
3R0	30R	300R	3K0	30K	300K	3M0	
3R3	33R	330R	3K3	33K	330K	3M3	
3R6	36R	360R	3K6	36K	360K	3M6	
3R9	39R	390R	3K9	39K	390K	3M9	
4R3	43R	430R	4K3	43K	430K	4M3	
4R7	47R	470R	4K7	47K	470K	4M7	
5R1	51R	510R	5K1	51K	510K	5M1	
5R6	56R	560R	5K6	56K	560K	5M6	
6R2	62R	620R	6K2	62K	620K	6M2	
6R8	68R	680R	6K8	68K	680K	6M8	
7R5	75R	750R	7K5	75K	750K	7M5	
8R2	82R	820R	8K2	82K	820K	8M2	
9R1	91R	910R	9K1	91K	910K	9M1	

Table 5-3: E24 series standard resistor values

E48 Series

The values of the decade 100-1000 for the E48 series are:

Standard resistor values (±2%) E48 Series							
100	105	110	115	121	127	133	140
147	154	162	169	178	187	196	205
215	226	237	249	261	274	287	301
316	332	348	365	383	402	422	442
464	487	511	536	562	590	619	649
681	715	750	787	825	866	909	953

Table 5-4: E48 series resistor standard values

Multiply or divide the values by 10 for other decades.

E96 Series

The values of the decade 100-1000 for the E96 series are:

Standard resistor values (±1%) E96 Series							
100	102	105	107	110	113	115	118
121	124	127	130	133	137	140	143
147	150	154	158	162	165	169	174
178	182	187	191	196	200	205	210
215	221	226	232	237	243	249	255
261	267	274	280	287	294	301	309
316	324	332	340	348	357	365	374
383	392	402	412	422	432	442	453
464	475	487	499	511	523	536	549
562	576	590	604	619	634	649	665
681	698	715	732	750	768	787	806
825	845	866	887	909	931	953	976

Table 5-5: E96 series resistor standard values

Multiply or divide the values by 10 for other decades.

E192 Series

The values of the decade 100-1000 for the E192 series are:

Standard resistor values (±0.5, ±0.25, ±0.1% and higher tolerances) E192 Series							
100	101	102	104	105	106	107	109
110	111	113	114	115	117	118	120
121	123	124	126	127	129	130	132
133	135	137	138	140	142	143	145
147	149	150	152	154	156	158	160
162	164	165	167	169	172	174	176
178	180	182	184	187	189	191	193
196	198	200	203	205	208	210	213
215	218	221	223	226	229	232	234
237	240	243	246	249	252	255	258
261	264	267	271	274	277	280	284
287	291	294	298	301	305	309	312
316	320	324	328	332	336	340	344
348	352	357	361	365	370	374	379

383	388	392	397	402	407	412	417
422	427	432	437	442	448	453	459
464	470	475	481	487	493	499	505
511	517	523	530	536	542	549	556
562	569	576	583	590	597	604	612
619	626	634	642	649	657	665	673
681	690	698	706	715	723	732	741
750	759	768	777	787	796	806	816
825	835	845	856	866	876	887	898
909	920	931	942	953	965	976	988

Table 5-6: E196 series resistor standard values

Multiply or divide the values by 10 for other decades.

When you are designing a circuit you need to round calculated resistor values to a preferred value. Normally this would be the value closest to the calculated one for the series you are using. However in some circumstances, it is better to round up to the next higher value, such as current limiting, resistors where using a value smaller than calculated could overload a component.

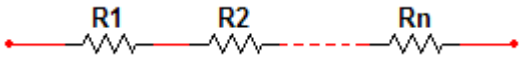
5. 1. 4. Resistor grouping

In circuit it is possible to have a resistor which is not found in standard resistor values and the change of it can have an effect on the whole circuit. The way out for this is recombine more than one resistor in such way they give the required value. The resistor can be grouped in series, parallel or mixt.

Series resistors

When resistors are connected in series, the resistor value add because each resistor offers opposition to the current in direct proportion to the its resistance. A greater number of resistors connected in series creates more opposition to current. More opposition to current implies a higher value of resistance. Thus for every resistance that is added in series, the total resistance increases.

In a series configuration, the current through all of the resistors is the same, but the voltage across each resistor will be in proportion to its resistance. The potential difference (voltage) seen across the network is the sum of those voltages, thus the total resistance can be found as the sum of those resistances:



$$R_{\text{eq}} = R_1 + R_2 + \cdots + R_n$$

As a special case, the resistance of N resistors connected in series, each of the same resistance R, is given by N*R.

Experiment 5-2: Measuring equal series resistors

Connect two equal resistors in series and measure the resulting resistance using Ohmmeter.

Part list

No	Item	Quantity
1	Ohmmeter	1
2	Fixed resistors 10K	3
3	Breadboard (mini board)	1
4	Wire (0.33mm^2)	5cm

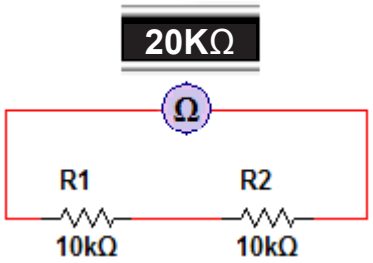


Figure 5-3: Circuit for measuring two equal series resistors

Procedure

1. Connect resistors as shown on breadboard circuit arrangement in figure 5-4
2. The first resistor (1-2) is in series with the second resistor (3-4) through a jumper wire (2-3)
3. Set multimeter in Ohm's range in higher value than expected to measure, for this experiment set in 200K or 50K if provided.

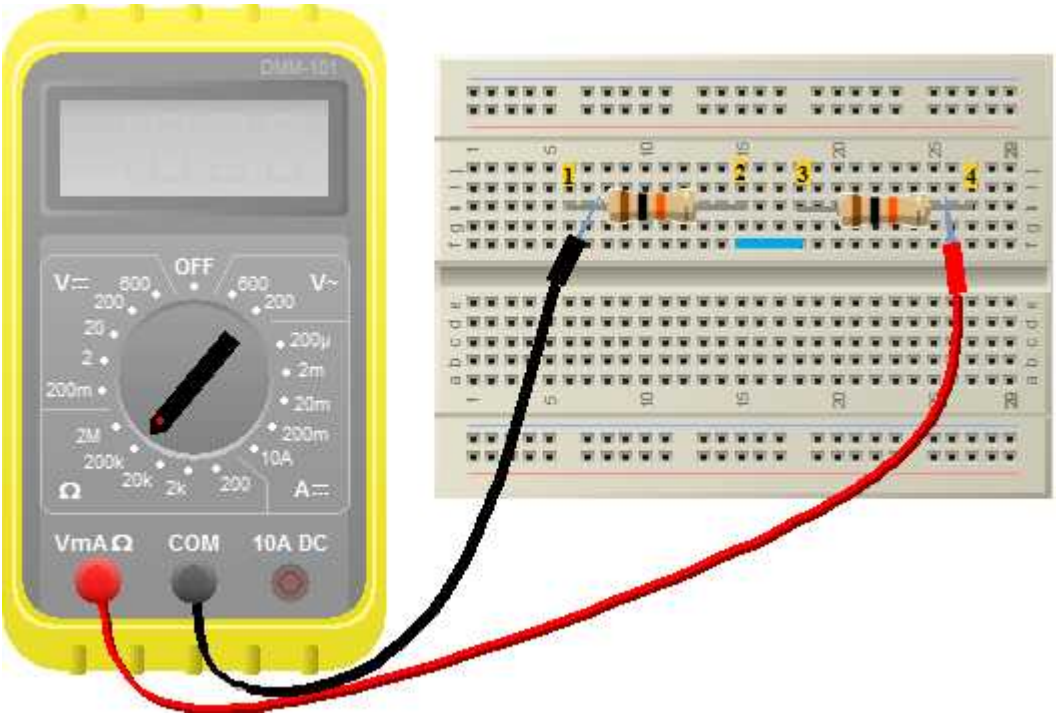


Figure 5-4: Measuring two equal series resistors

4. Hold multimeter's lead against the end terminals of the series connected resistors (1-4)
5. The displayed value is about 20K despite the value deviation caused by tolerance and the atmosphere condition.

Note: Remember to use fresh battery of the multimeter otherwise the obtained value can be erroneous. The polarity does not matter when you are measuring resistance.

Connect three equal resistors in series and measure the resulting resistance using Ohmmeter.

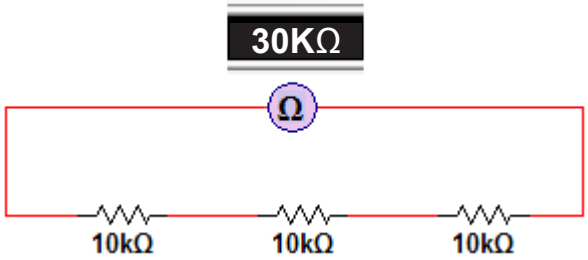


Figure 5-5: Circuit for measuring three equal series resistors

Procedure

1. Connect resistors as shown on breadboard circuit arrangement figure 5-6
2. The first resistor (1-2) is in series with the second resistor (3-4) both in series with the third resistor (5-6) all interconnected through the jumper wires (2-3) and (4-5)

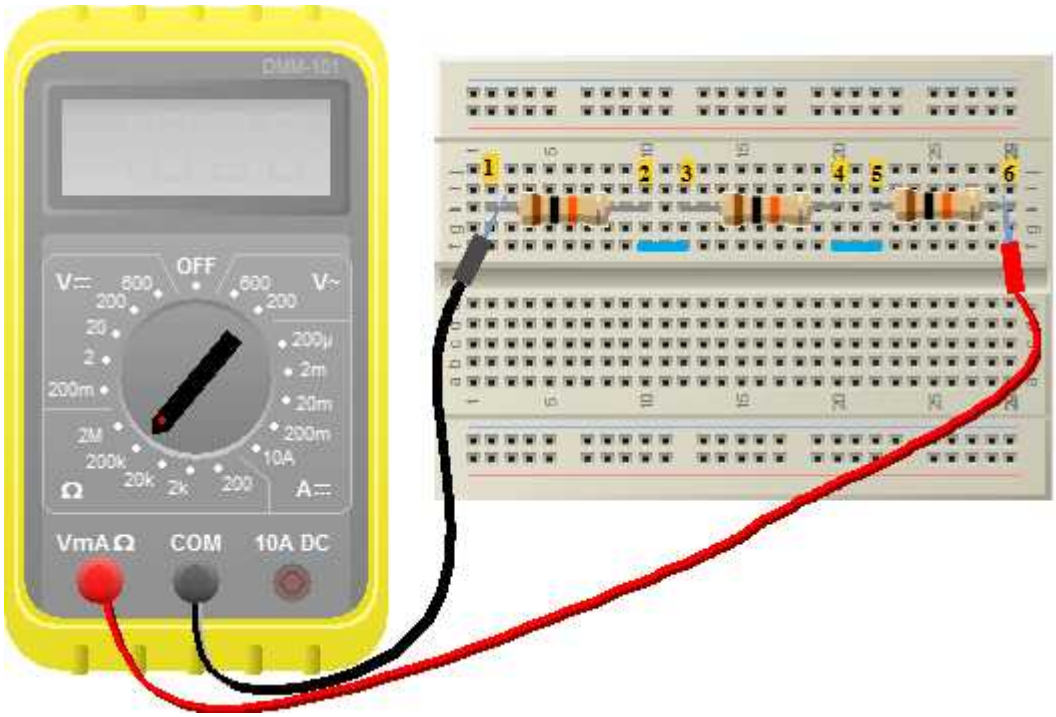


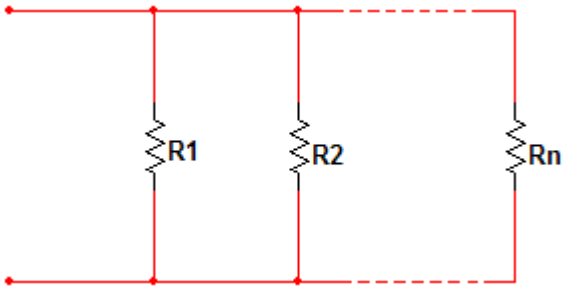
Figure 5-6: Circuit connection for measuring three equal series resistors

3. Set multimeter in Ohm's range in higher value than expected to measure, for this experiment set in 50K scale.
4. Hold multimeter's lead against the end terminals of the series connected resistors (1-6)
5. The displayed value is about 30K despite the value deviation caused by tolerance and the atmosphere condition.
6. The use of drained battery can lead to the wrong value reading
7. The atmosphere condition such as heat and cold can affect on resistors properties where the value reading mistake.

As result, connecting any equal resistors in series their equivalent resistance equal to one resistor multiply the number of series connected equal resitors.

5. 1. 4. 2. Parallel resistors

When two or more resistors are individually connected between the same two points, they are in parallel with each other. A parallel circuit provides more than one path for current. Resistors in a parallel configuration are each subjected to the same potential difference (voltage), however the current through them add. The conductance of the resistors then add to determine the conductance of the network. Thus the equivalent resistance (Req) of the network can be computed.



$$1/R_{eq} = 1/R_1 + 1/R_2 + \ldots + 1/R_n$$

The parallel equivalent resistance can be represented in equations by two vertical lines "||" (as in geometry) as a simplified notation. Occasionally two slashes "//" are used instead of "||", in case the keyboard or font lacks the vertical line symbol. For the case of two resistors in parallel, this can be calculated using:

$$R_{eq} = R_1 \parallel R_2 = (R_1 * R_2)/(R_1 + R_2)$$

As a special case, the resistance of N resistors connected in parallel, each of the same resistance R, is given by R/N.

Experiment 5-3: Measuring equal parallel resistors

Part list

No	Item	Quantity
1	Ohmmeter	1
2	Resistor 2x10K, 3x15K	5

3	Breadboard (mini board)	1

Connect two equal resistors in parallel and measure the resulting resistance using Ohmmeter.

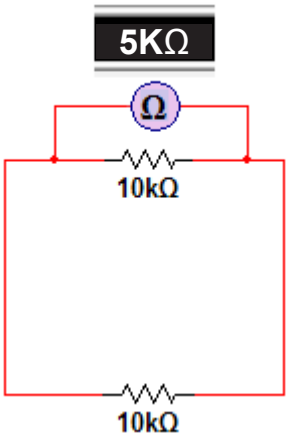


Figure 5-7: Circuit for measuring two equal resistors

Hands on tip

When measuring a resistance, make sure you do not touch the meter leads or the resistor leads. If you hold both ends of a high-value resistor in your fingers along with the meter probes, the measurement will be inaccurate because your body resistance can affect the measured value. When body resistance is placed in parallel with a high-value resistor, the measured value will be less than the actual value of resistor.

Procedure

1. Connect resistors as shown on breadboard circuit arrangement figure 5-8
2. All the three resistors terminals of the same side are connected together (1-2)

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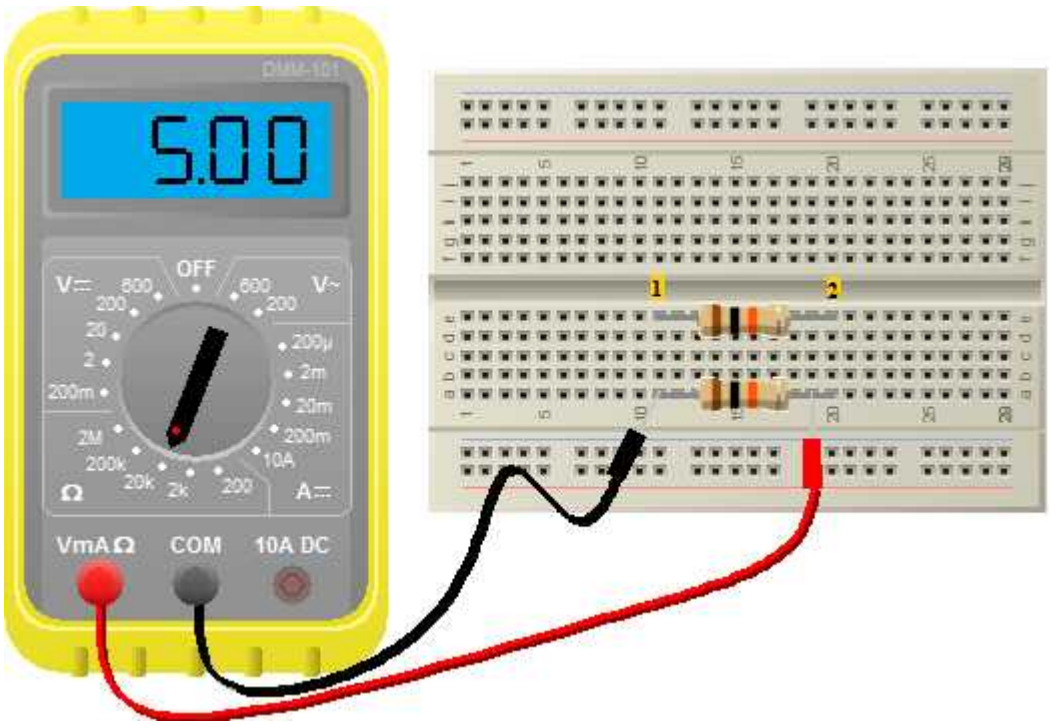


Figure 5-8: Circuit connection for measuring two equal parallel resistors

3. Set multimeter in Ohm's range in higher value than expected to measure, for this experiment set in 10K or 20K scale
4. Hold multimeter's lead against the end terminals of the parallel connected resistors (1-2)
5. The displayed value is about 5K despite the value deviation caused by tolerance and the atmosphere condition.

Note: Remember to use fresh battery of multimeter

Connect three equal resistors in parallel and measure the resulting resistance using Ohmmeter.

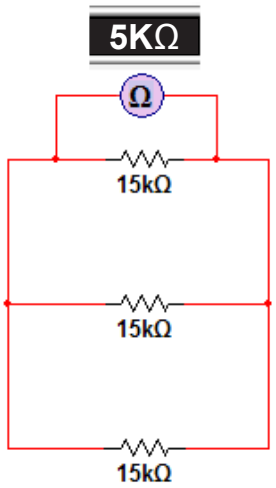


Figure 5-9: Circuit for measuring three equal parallel resistors

Procedure

1. Connect resistors as shown on breadboard circuit arrangement figure 5-10
2. All terminals of the first resistor and that of the second are connected together (1-2)
3. Set multimeter in Ohm's range in higher value than expected to measure, for this experiment set in 10K or 20K scale
4. Hold multimeter's lead against the end terminals of the parallel connected resistors (1-2)
5. The displayed value is about 5K despite the value deviation caused by tolerance and the atmosphere condition.
6. Remember to use multimeter's fresh battery

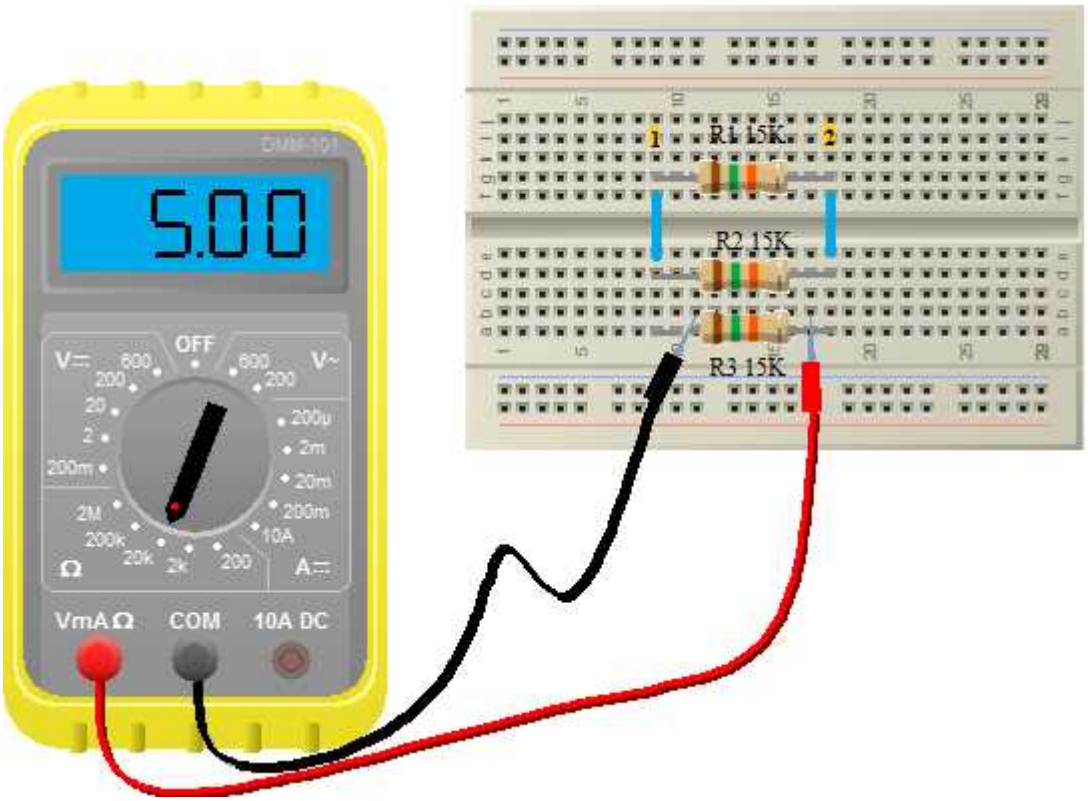
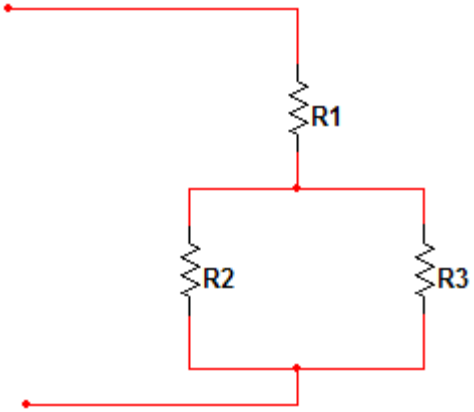


Figure 5-10: Circuit connection for measuring three equal parallel resistors

Series and Parallel Resistors

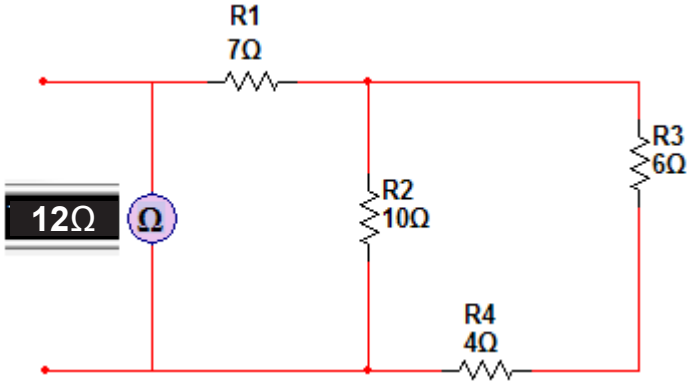
A resistor network is a combination of parallel and series connections that can be broken up into smaller parts that are either one or the other. A series-parallel circuit consists of combinations of both series and parallel current path. It is important to be able to identify how the components in a circuit are arranged in terms of their series and parallel relationships. The analysis of series-parallel circuits can be approached in many ways, depending on information you need and what circuit values you know. The examples in this section do not represent an exhaustive coverage, but they give you an idea of how to approach series-parallel circuit analysis

Circuit example



$$R_{eq}=(R_2 \| R_3)+R_1$$
$$=(R_2*R_3)/(R_2+R_3)+R_1$$

However, some complex networks of resistors cannot be resolved in this manner, requiring more sophisticated circuit analysis.

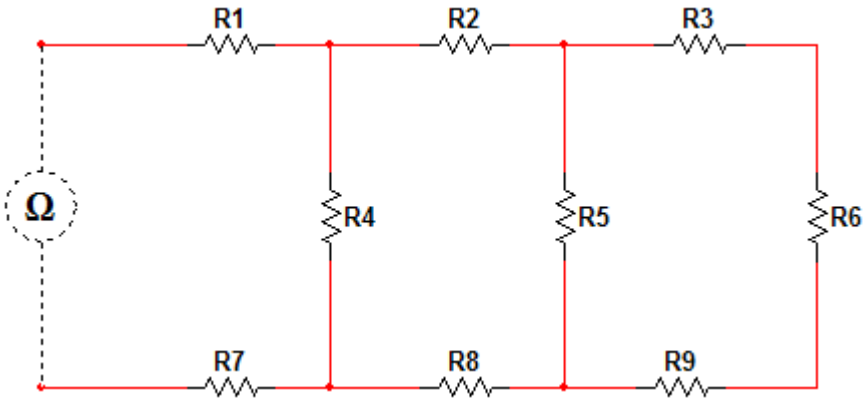


$R_{34}=R_3+R_4=6\Omega+4\Omega=10\Omega$

$R_{34} \| R_2=(R_{34}*R_2)/ (R_{34}+R_2)= (1\ \Omega*10\Omega)/ (10\Omega+10\Omega)=5\Omega$

$R_{eq}= R_{34} \| R_2+R_1=5\Omega+7\Omega=12\Omega$

Do the next circuit as your exercise. This is a bit complicated than the above circuit problem. The application is still the same. Given that R_1= 1 ohm, R_2= 2 ohms, R_3= 3 ohms, R_4= 4 ohms, R_5= 5 ohms, R_6= 6 ohms, R_7= 7 ohms, R_8= 8 ohms and R_9= 9 ohms. What will be the total resistance of the circuit below?



Note that resistors are constructed respecting standard values. This implies that you cannot get a resistor of 17.3K, 23.5K or fractional resistance on market.

Experiment 5-4: Series and Parallel Resistors (current and voltage measuring)

The objective of this experiment is to verify Ohm's law applied to

1. Series resistors (experimentally verifying that they experience the same current),
2. Parallel resistors (experimentally verifying that they experience the same voltage), and
3. A module of parallel resistors collectively in series with another resistor.

Part list

No	Items	Specifications	Quantity
1	Multimeter	Digital multimeter	2
2	Resistor	1 kΩ	1
3	Wire	22-gauge (0.33mm^2) solid wire	40cm
4	Breadboard	Prototyping board	1
5	Battery	9V dc supply	1

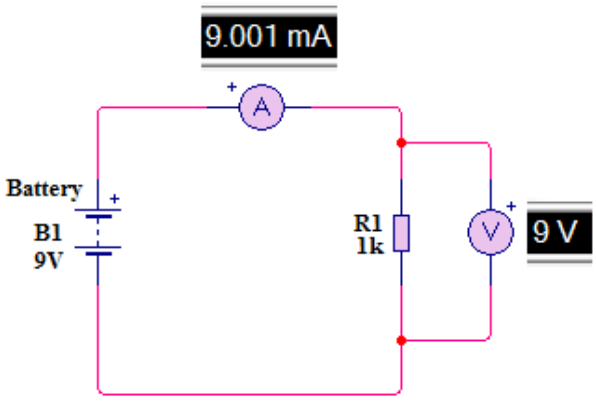


Figure 5-11: Circuit for measuring current and voltage

Ohm's Law of Electricity

Ohm's law of Electricity states that the current through a conductor between two points is directly proportional to the potention difference across the two points, and inversely proportional to the resistance between them. it can be represented by equation I=V/R where I is the current through the conductor in amperes, V is the potential difference measured across the conductor volts, and R is the resistance of the conductor in Ohms.

With Ohms's law: I=V/R

Therefore

I = V/R = 9V/1000Ω = 0.009A

Procedure

1. Connect the circuit as illustrated in figure 5-12
2. Set ammeter in DC amps range at 20mA scale
3. The ammeter is connected in series with the circuit (2-3)
4. Set the voltmeter in DC volts range at 20V scale
5. Voltmeter is connecter in parallel with R1 resistor (3-4)
6. Supply the circuit with DC source; positive of the battery at power bus (1) and connected to the red lead of the ammeter through a jumper wire (1-2), the negative of the battery at ground bus of breadboard (5-6) and connected to one terminal of a resistor R_1 and black lead of voltmeter through a jumper wire (4-5)

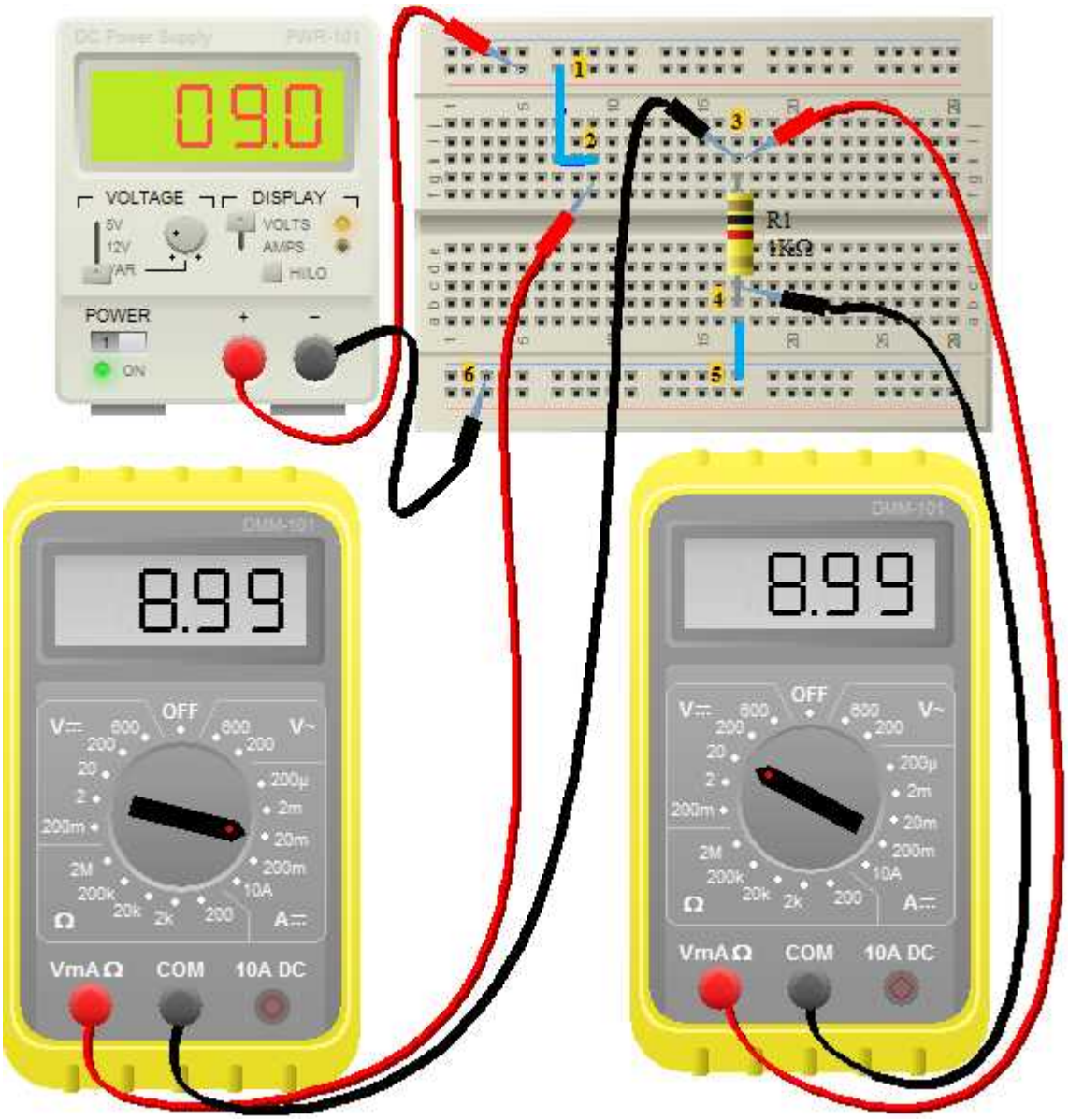


Figure 5-12: Circuit connection for measuring current and voltage

Experiment 5-5: Measuring current and voltage across Series Resistors

For series-connected resistors, Figure 5-14), the equivalent resistance (R_{equ}) is calculated using the following equation: $R_{eq}=R_1+R_2$ and current $I=V_{battery}/R_{equ}$.

Part list

No	Items	Specifications	Quantity
1	1 Ammeter, 2Voltmeter	Digital multimeter	3
2	Resistor	1kΩ and 560Ω	2
3	Connecting wire	22-gauge (0.33mm^2) solid wire	40cm

4	Breadboard	Prototyping board (mini board)	1
5	9V dc supply	9V Battery	1

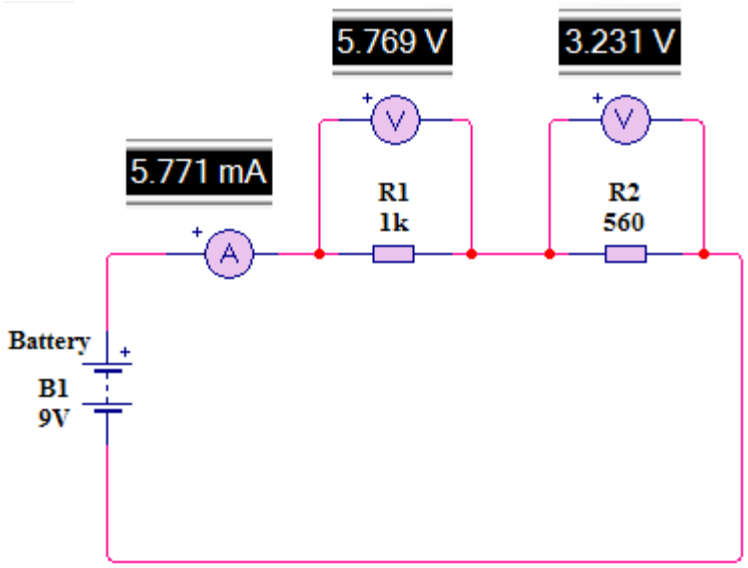


Figure 5-13: Circuit for measuring current and voltage across two resistors

By Ohm's law, I=V/R and V=R*I

$R_{eq}=R_1+R_2$

=1K+560R =1.56K =1560R

Total current $I=V_{B1}/R_{eq}$

=9V/1560 =0.005769A

Voltage on R_1 (V_{R1}) =I*R_1

=1000R*0.005769A =5.769V

Voltage on R_2 (V_{R2})=I*R_2

=0.005769A*560R =3.23064V

Procedure

1. Connect the circuit as illustrated in figure 5-14
2. Set ammeter in DC amps range at 20mA scale
3. The ammeter is connected in series with the circuit (1-2); the red lead is connected to the positive of the battery and black lead on one terminal of resistor R_1 through a jumper wire (2-3)
4. Set both voltmeters in DC volts range at 20V scale
5. One voltmeter is connecter in parallel with R_1 resistor (3-4) and the other in parallel with R_2 resistor (5-6)

6. Supply the circuit with DC source; positive of the battery to the power bus of breadboard (1) and the negative of the battery at ground bus of breadboard (7-8) and connected to one terminal of a resistor R_1 and black lead of voltmeter through a jumper wire (6-7)

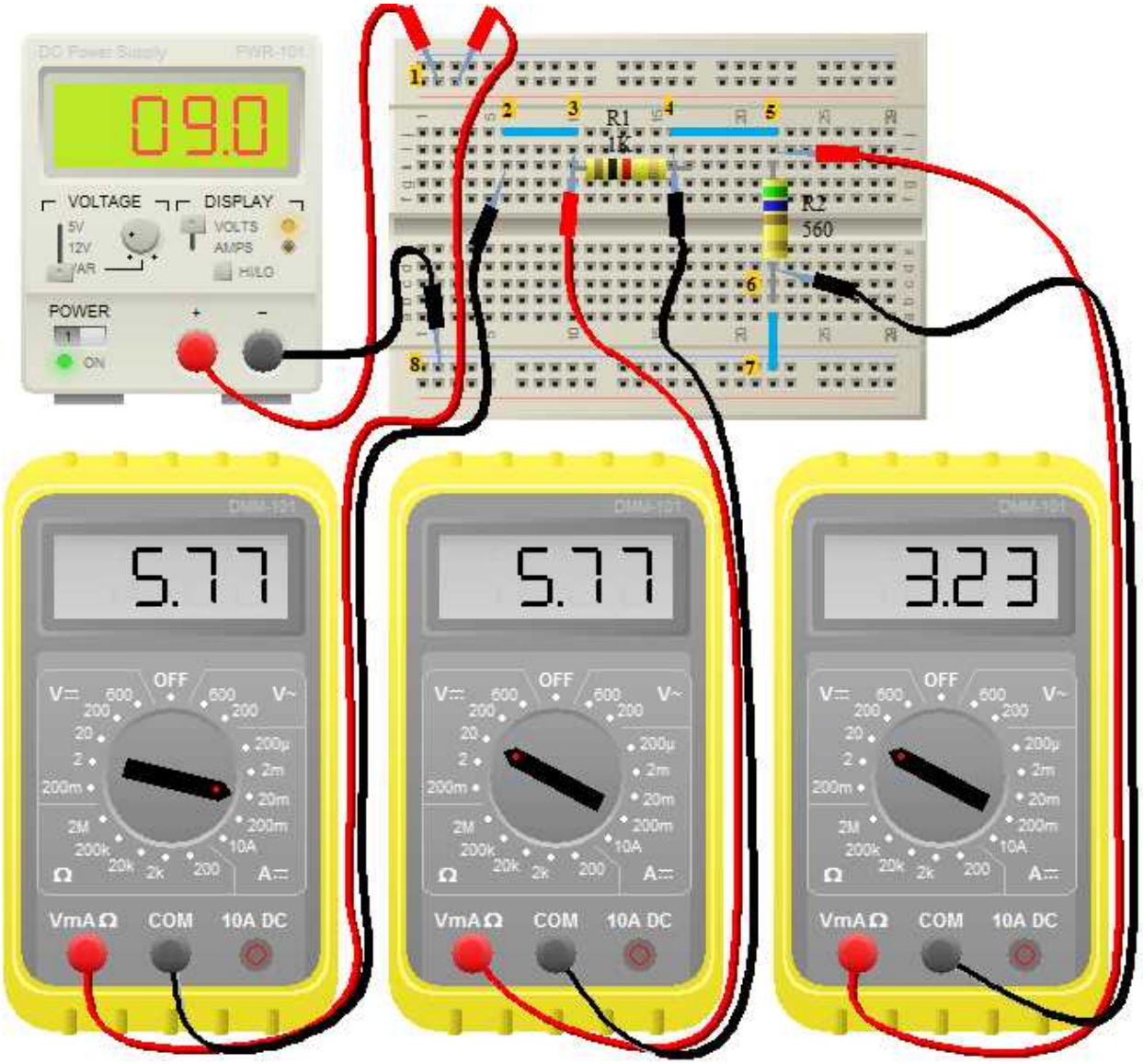


Figure 5-14: Circuit connection for measuring current and voltage

5. 1. 5. Potentiometer

A potentiometer or pot for short is a variable resistor with three terminals. Two of the terminals are permanently fixed on each end of the resistor, but the middle terminal is connected to a wiper that slides in contact with the entire surface of the resistor. Thus, the amount of resistance between this center terminal and either of the two side terminals varies as the wiper moves. Potentiometer in schematic diagrams is an arrow pointing at the center tap of the resistor. It is meant to reflect that the value of the resistance at this terminal varies when the wiper moves.

(1) (2)

Figure 5-15: American potentiometer symbol (1), European potentiometer symbol (2)

Potentiometer Markings.

The code to indicate the resistance and law of a potentiometer in case of replacement and even it would have been so bad if there was no overlap between the "old" and "new" "standards" the table 5-7 indicates standard notation.

Taper	Old Code	New Code	Alternate
Linear	A	B	LIN
Log (Audio)	C	A	LOG
Antilog	F	N/A	N/A

Table 5-7: Potentiometer markings

It is obviously important to check before you make assumptions, or you can easily get the wrong type especially if working on older equipment.

There is a much smaller range of potentiometer values, always in a 1, 2.5, 5 sequence. Common values for panel pots are 1k, 5k, 10k, 25k, 50k, 100k, 500k and 1M. Potentiometer with 2.5k and 250k went missing along the way, and these are not stocked by many distributors. 25k pots are becoming harder to get as well. Not all values are available in log and linear, and in some cases you may even find that for a particular type, you can get them in any value you want, as long as it is 100k (for example). The only way to know what you can get from your local supplier is to check their catalogue. In reality, everything is available, but you may have to go a very long way to get it.

Experiment 5-6: Measuring the resistance of a Potentiometer

Potentiometer is a three terminal device used to vary the resistance in any circuit and the shaft is attached with it to vary the resistance. Many people use potentiometer in their day to day life, for example varying the volume of your music system by rotating the knob, controlling the brightness of television by pressing a button on the remote.

This tutorial will explain how to measure the resistance of the potentiometer by using digital multimeter for its accurate value.

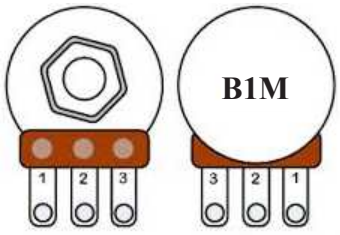
Part list

No	Item	Specification	Quantity
1	Ohmmeter	Digital multimeter	1
2	Linear potentiometer	B1M	1

Procedure:

Step 1: Knowing the potentiometer

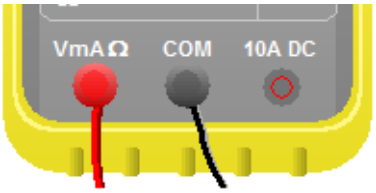
Turn the potentiometer and you will see the maximum resistance value of the potentiometer engraved over it. Here 1Mega ohm is the maximum value of resistance for this potentiometer.



Front view **Back view**

Step 2: Making connections to the multimeter

Connect the multimeter probes according to their polarity. The red wire goes to the positive while the black one goes to the ground or neutral.



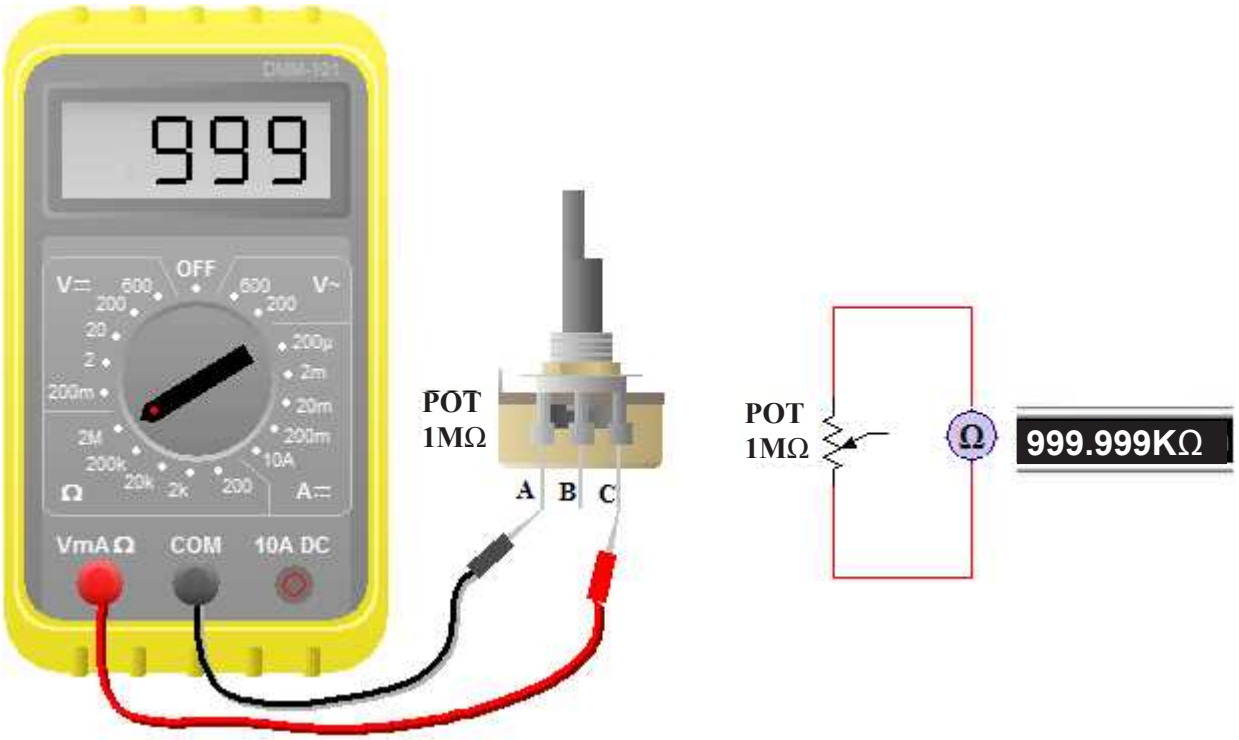
Step 3: Adjusting the multimeter for measuring resistance

For most multimeters, 2M ohm is the starting range for measuring resistance in Mega ohms. As our pot is of 1 Mega Ohm, 2M ohm range is more than sufficient to measure 1 Mega ohm.

Step 4: Measuring the total resistance of the potentiometer

We can see the maximum resistance of this potentiometer by connecting the probes at both the ends.

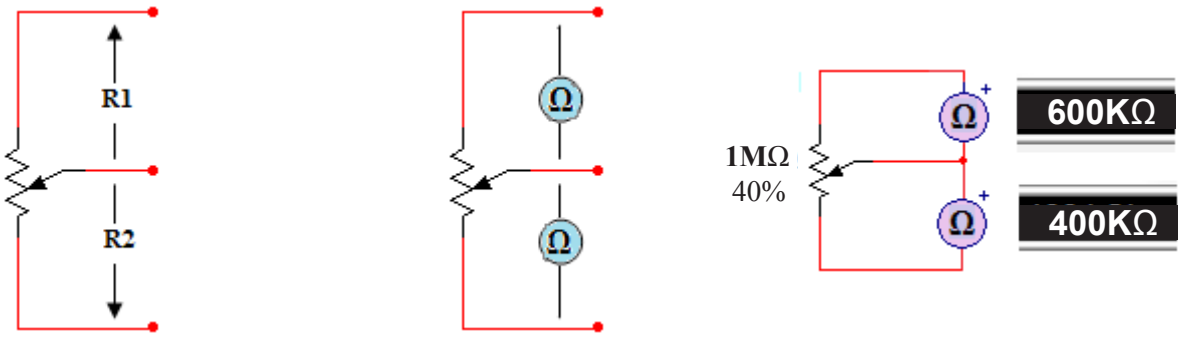
Here 999.999 KΩ is the maximum resistance of this potentiometer. The measuring range of the multimeter is the same as what we have seen in the Step 2.



Potentiometer can be either angular (rotational) or linear (slider type) in its movement. Thus, the amount of resistance between the wiper and either of the two side terminals varies as the wiper moves. The long handle on the potentiometer / variable resistor can be turned clockwise or anti-clockwise, altering the value of the resistance. The range of movement of its wiper or slider (and hence the output obtained) is limited to the physical size of the potentiometer being used.

Step 5: Connecting probes to the lugs of potentiometer.

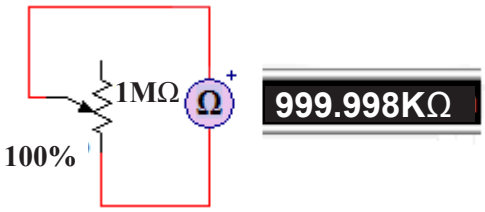
The positive probe is connected to the middle lug while the negative probe is connected to the first lug.



Position of the lugs can be changed but it will affect the change of resistance i.e. changing the terminals will change the minimum and maximum point of the resistance.

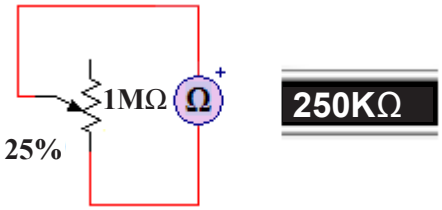
Step 6: Maximum resistance

The knob is turned to its maximum position and by connecting the probes to the terminals of the potentiometer; digital multimeter displays the value of resistance.



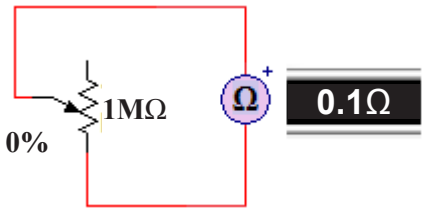
Step 7: Varying the resistance

The knob of the potentiometer is turned anticlockwise and the resistance of the potentiometer is decreased.



Step 8: Minimum resistance

As the knob is rotated to its minimum position resistance also comes to its minimum value.



Note that if only two terminals of potentiometer are used, one end and the wiper, it acts as a variable resistor or rheostat.

Hands on tip

The volume control of a radio receiver is a common application of a potentiometer used as voltage divider. Since the loudness of the sound is dependent on the amount of voltage associated with the radio signal, you can increase or decrease the volume by adjusting the potentiometer, that is, by tuning the knob of the volume control on the set.

Dimmer switch

Dimmer switch is used to show how the brightness of the bulb is related to the current flowing through the bulb simply by using potentiometer connected as rheostat as shown in the circuit figure 5-16. Variable resistors are designed so that their resistance values can be changed easily with a manual or automatic adjustment. As resistance increases, the current decreases and also the brightness of the bulb decreases and vice versa.

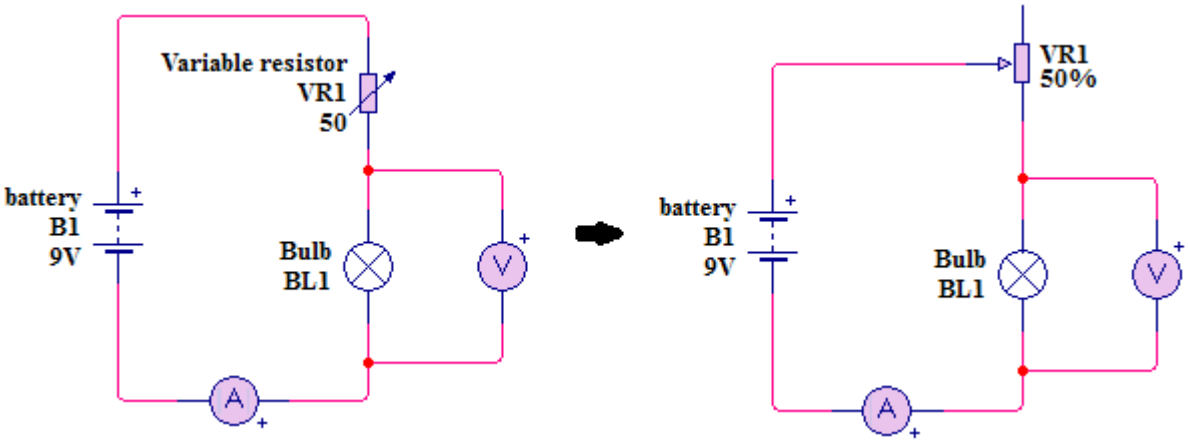
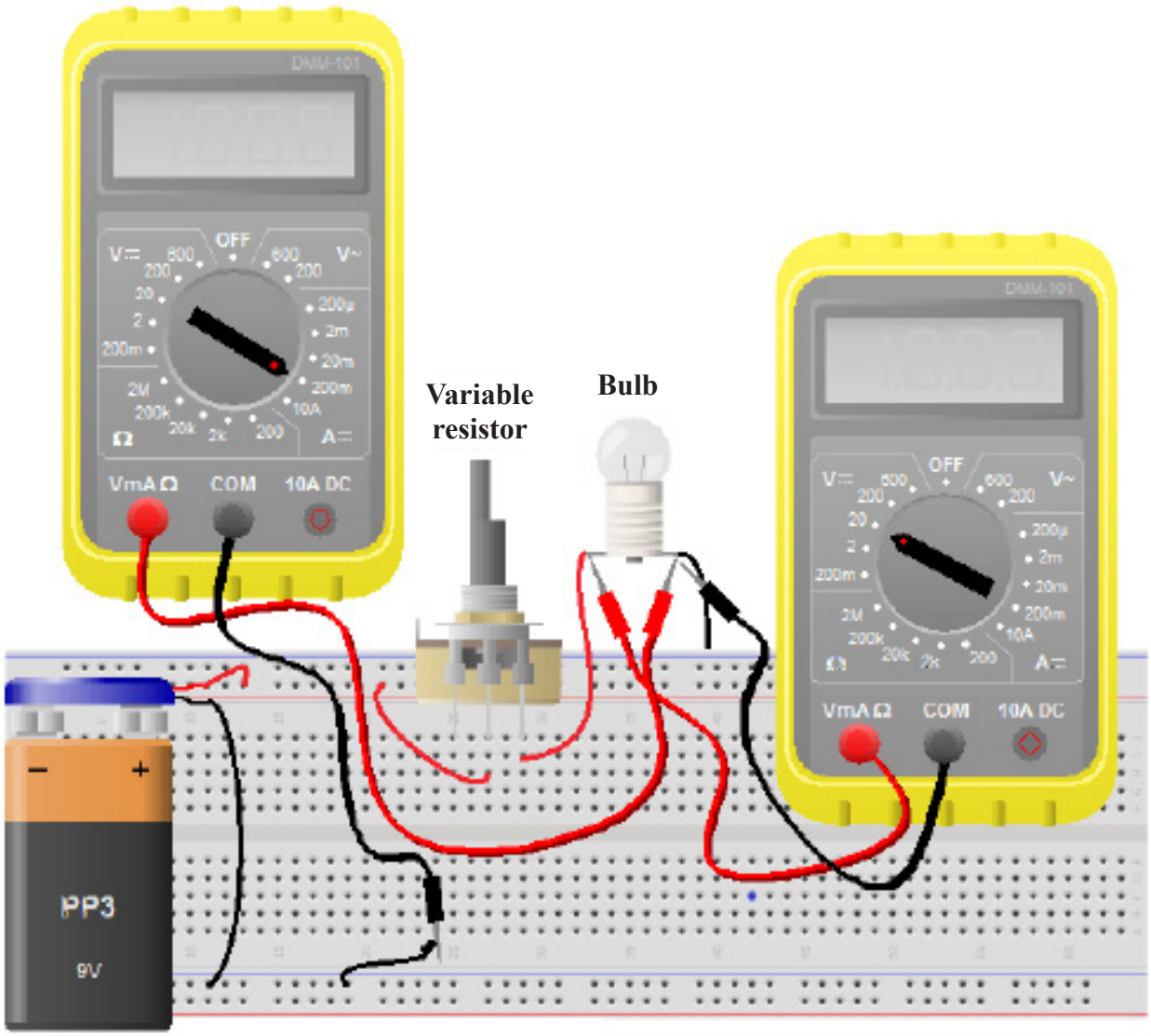


Figure 5-16: Dimmer circuit



chap 5

Figure 5-17: Dimmer circuit connection

Hands on tip

A potentiometer is a variable resistor with three terminals. A potentiometer acts as voltage divider when only one end and adjustable terminal or wiper are used.

When you are using a multimeter, such as analog or digital multimeter, when you manually select the voltage and current ranges, it is good practice to always set the multimeter on the maximum range before you measure an unknown voltage or current. You can then reduce the range until you get an acceptable reading.

5. 1. 6. Trimmer Resistor

A trimmer resistor usually called a trim pot or preset potentiometer is a small variable resistor that is used in circuits to do preset. It is trimmed with a trimmer screwdriver it is made up with a round fiber disc with a layer of carbon with a wiper that run on the carbon layer to change the resistance it always have 3 connecting pins where the center one is connected to the wiper and the other two to opposite ends of the carbon strip. Resistance trimmers are required when the value of resistance or voltage division in a circuit must be adjusted to compensate for environmental influences, when the desired circuit performance cannot be procured and retained through manufacturing, or it is unknown what precision is required. This applies to precision applications, among others.

(1) (1)

Figure 5-19: American trimmer resistor symbol (1), European trimmer resistor symbol (2)

Figure 5-18: Examples of typical commercial trimmer resistors

Trimmer codes labeling value identification

Trimmer resistance value is taken to mean from digits codes written to them. These codes can be in the form of two or three digits.

Two digits Trimmer resistor codes

In principle, when two digits are used, the first digit represents significant digit of ohm unit while the second digit represents a number of zeros following the significant figure. The table 5-8 shows the common values.

Nominal resistance values (Ω)	Code	Nominal resistance values (Ω)	Code
10	11	**10K**	14
20	21	**20K**	24
50	51	**3K**	34
100	12	**5K**	54

200	22	**100K**	15
300	32	**200K**	25
500	52	**500K**	55
1K	13	**1M**	16
2K	23	**2M**	23
3K	33	-	-
5K	53	-	-

Table 5-8: Two digits Trimmer resistor codes

Three digits Trimmer resistor codes

In principle, when 3 digits are used, the first and second digits represent significant figures of ohm unit while the last digit represents a number of zeros following the significant figures. The table 5-9 describes the common encountered values.

Nominal resistance values (Ω)	Code	Nominal resistance values (Ω)	Code
10	100	**10K**	103
20	200	**20K**	203
-	-	**25K**	253
50	500	**50K**	503
100	101	**100K**	104
200	201	**200K**	204
-	-	**250K**	254
500	501	**500K**	504
1K	102	**1M**	105
2K	202	**2M**	205
5K	502	**5M**	505

Table 5-9: Three digits Trimmer resistor codes

5. 1. 7. Resistor Power Ratings

Practical resistors are specified as having a maximum power rating which must exceed the anticipated power dissipation of that resistor in a particular circuit: this is mainly of concern in power electronics applications.

Figure 5-20: 1/2 watt resistor and 1 watt resistor

Resistors with higher power ratings are physically larger and may require heat sinks. In a high-voltage circuit, attention must sometimes be paid to the rated maximum working voltage of the

resistor.

Resistors are available with power ratings of 1/8th W (or less for surface mount devices), up to hundreds of watts. The most common are 1/4W (0.25W), 1/2W (0.5W), 1W, 5W and 10W.

5. 2. Capacitor

A capacitor is an electronic passive component consisting of a pair of conductors separated by a dielectric. A capacitor can store energy in the electrical field between a pair of conductors called "plates". When a voltage potential difference exists between the conductors, an electric field is present in the dielectric. This field stores energy and produces a mechanical force between the plates. The process of storing energy in the capacitor is known as "charging", and involves electric charges of equal magnitude, but opposite polarity, building up on each plate. The effect is greatest between wide, flat, parallel, narrowly separated conductors.

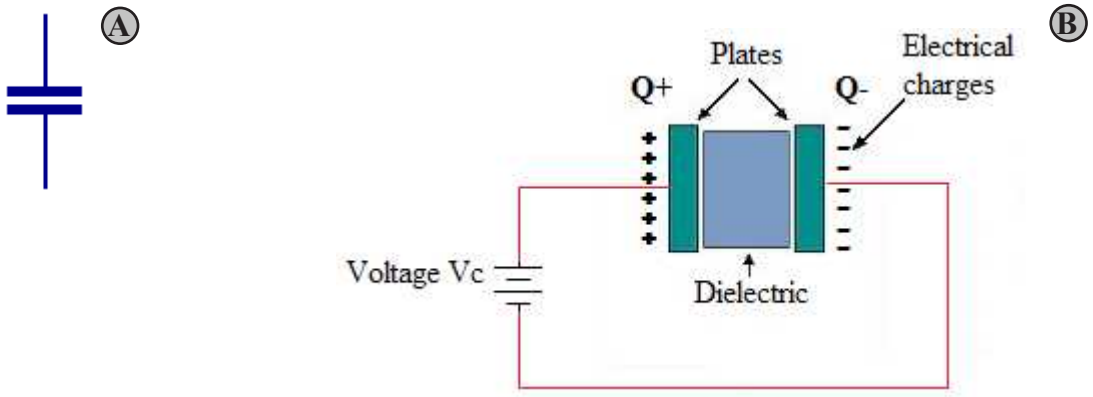


Figure 5-21: Capacitor symbol (A) and capacitor structure (B)

Capacitors store electrical energy between two internal "plates," or conductors. They are commonly used to help differentiate between high and low frequencies in signal-carrying circuitry. They can be made of several different materials to produce varying levels of capacitance.

Charging a Capacitor

A capacitor will charge when it is connected to a dc voltage source. The capacitor in figure 5-22 part (a) is uncharged; that is, plate A and plate B have equal numbers of free electrons. When the switch is closed, in figure 5-22 part (b), the source moves electrons away from plate A through the circuit to the plate B as the arrows indicate.

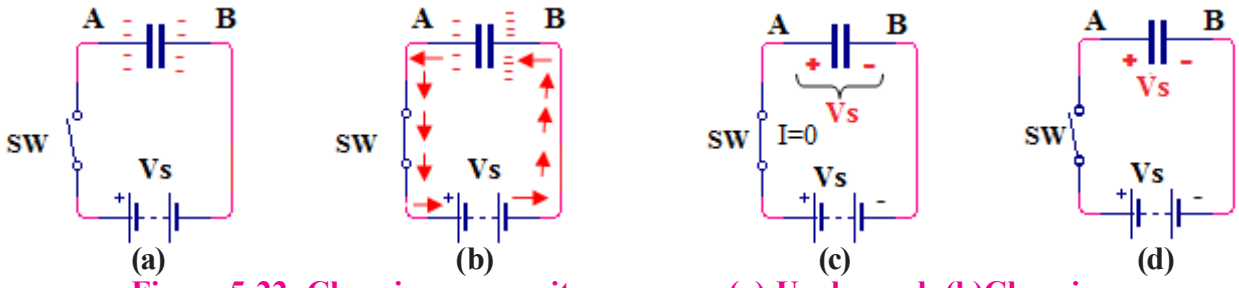


Figure 5-22: Charging a capacitor process. (a) Uncharged, (b)Charging, (c) Fully charged, (d) retains charge

As plate A loses electrons and plate B gains electrons, plate A becomes positive with respect to the plate B.

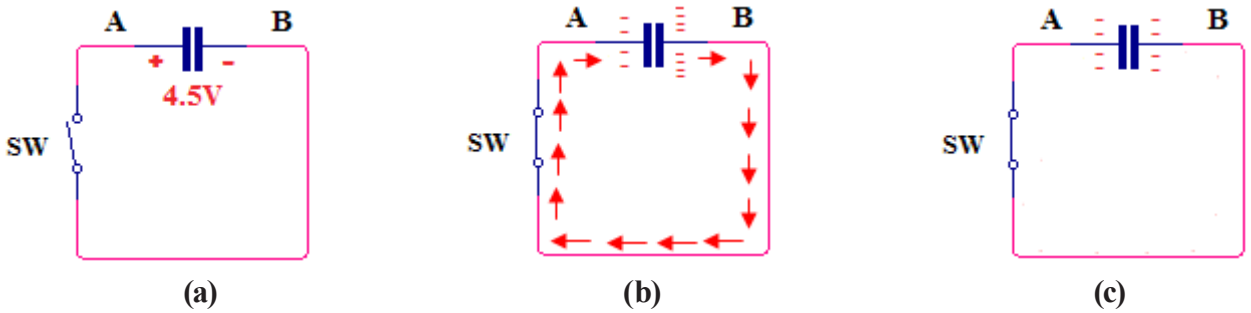
As this charging process continues, the voltage across the plates builds up rapidly until it is equal to the source voltage, Vs, but opposite in polarity, as shown in figure 5-22 part (c). when the capacitor is fully charged, there is no current.

A capacitor blocks a constant dc. When the charged capacitor is disconnected from the source, as shown in figure 5-22 part (d), it remain charged for long periods of time, depending on its leakage resistance. The charge on an electrolytic capacitor generally leaks off rapidly than in other types of capacitor.

The portion of total charge that is stored by a capacitor depends on its capacitance value and the voltage applied according to the relationship Q=CV

Discharging a Capacitor

When a conductor or a resistive material is connected across a charged capacitor, the capacitor will discharge. In a particular case, a very low resistance path (conductor) is connected across the capacitor with a switch. Before a switch is closed, the capacitor is charged to 4.5V, as indicated in figure 5-23 part (a).



(a) (b) (c)

Figure 5-23: Discharging a capacitor process. (a) Charged capacitor, (b) Discharging, (c) Full discharged

When the switch is closed, as shown in figure 5-23 part (b), the excess electrons on plate B moves through the circuit to plate A (indicated by the arrows); as a result of the current through the low resistance of the conductor, the energy stored by the capacitor is dissipated in the resistance of the conductor. The charge is neutralized when the number of free electrons on both plates are again equal. At this time, the voltage across the capacitor is zero, and the capacitor is completely discharged, as shown in figure 5-23 part (c). Notice that the direction of electron flow during discharge is opposite to that during charging. It is important to understand that, ideally, *there is no current through the dielectric of the capacitor during charging or discharging because the dielectric is an insulating material.* There is current from one plate to the other only through the external circuit.

Experiment 5-7: Charging and discharging of capacitor

This experiment help to understand the charging and discharging processes of capacitor. Large value capacitors are required for this experiment to produce time constants slow enough so that the time of charging and discharging be visible on oscilloscope. Capacitors to be used are of the "electrolytic" type, and they are polarized as well. One terminal of each capacitor should be marked with a definite polarity sign. Usually capacitors of the size specified have a negative (-) marking or

series of negative markings pointing toward the negative terminal. Very large capacitors are often polarity-labeled by a positive (+) marking next to one terminal. Failure to heed proper polarity will almost surely result in capacitor failure, even with a source voltage as low as 4.5 volts. When electrolytic capacitors fail, they typically explode, spewing caustic chemicals and emitting foul odors.

Build the circuit and observe voltage variation across the capacitor by changing the position of switch and notice how it increases and decreases slowly over time. You can "reset" the capacitor back to a voltage of zero by shorting across its terminals with a piece of wire.

Part list

No	Item	Quantity
1	Oscilloscope	1
2	Resistor 1K	1
3	Breadboard (RSR 03MB102)	1
4	SPDT toggle switch	1
5	Electrolytic capacitor 470uF/50V	1
6	Wire 0.33mm^2	10cm
7	3x1.5V cell battery or use 4.5V DC supply	1

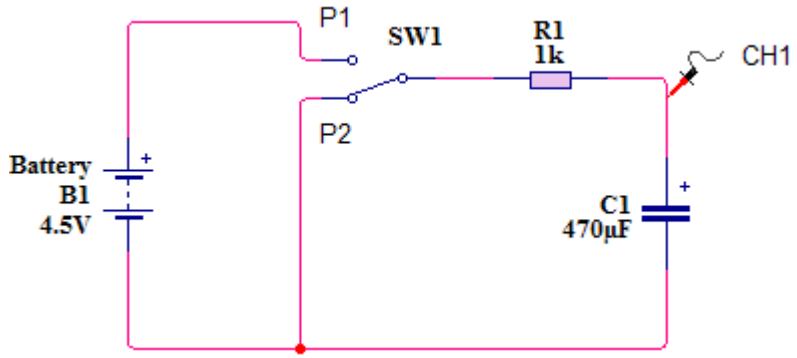


Figure 5-24: Circuit for charging and discharging a capacitor

The charging time takes place when switch SW1 is at position 1 (P1) while discharging time takes place when the switch SW1 is at position 2 (P2). The time constant determines the duration of charging and discharging processes. The "time constant" (τ =RC) of a resistor capacitor circuit is calculated by taking the circuit resistance and multiply it by the circuit capacitance. For a 1kΩ resistor and a 1000µF capacitor, the time constant should be 1 second. This is the amount of time it takes for the capacitor voltage to increase approximately 63.2% from its present value to its final value which is the voltage of the battery. For the above circuit figure 5-24 it takes 0.4 second. Normally a one-second time constant doesn't provide much time to take voltmeter readings but for oscilloscope it is possible to change time/division. We can increase this circuit's time constant two different ways: changing the total circuit resistance, and/or changing the total circuit capacitance. Let's observe circuit connection figure 5-25.

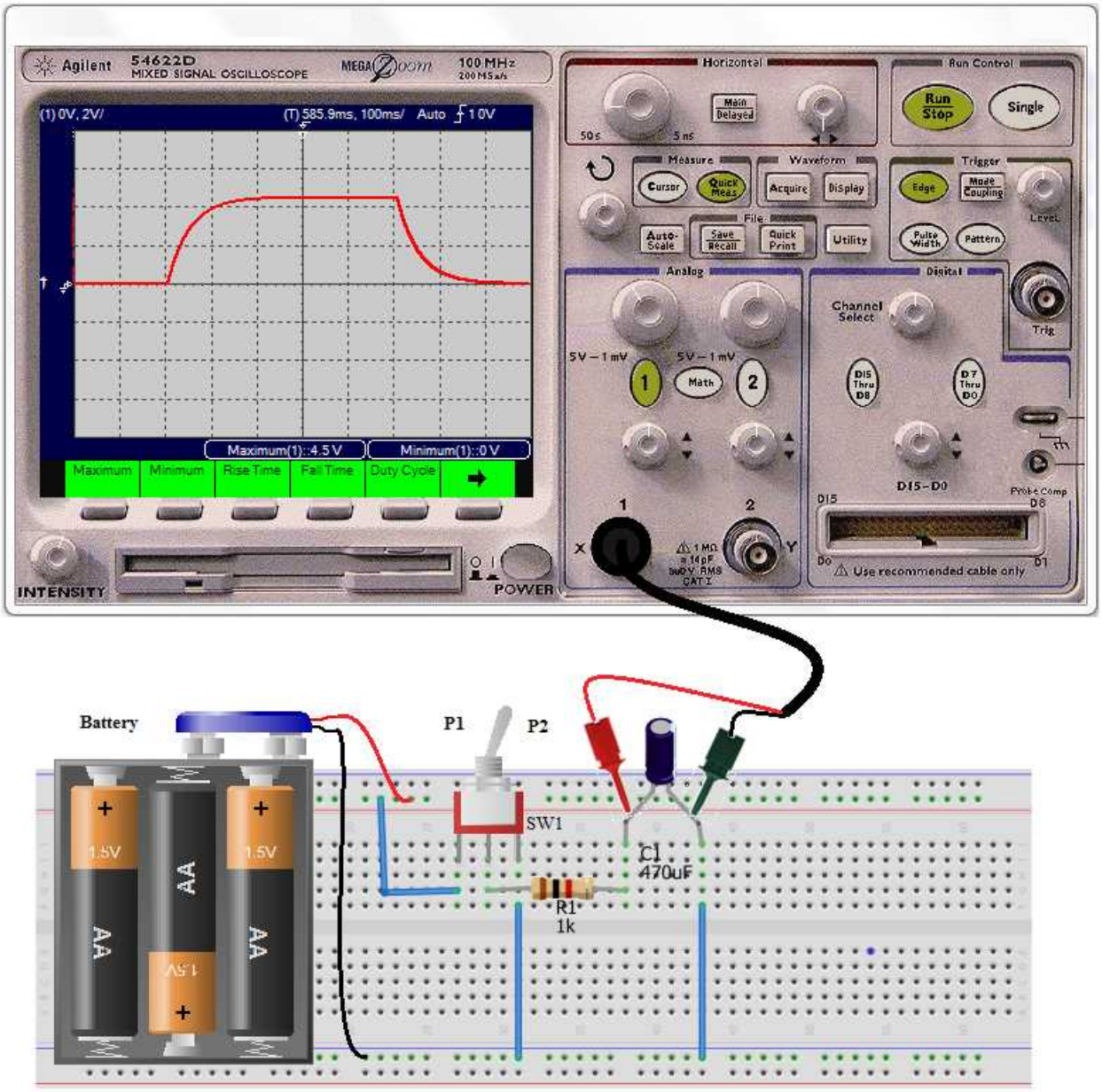


Figure 5-25: Circuit connection for charging and discharging of a capacitor

Procedure

1. Connect circuit as shown in the circuit figure 5-25 by using specified items
2. Check electrolytic capacitor's polarities
3. First discharge capacitor by shorting its terminals
4. Supply the circuit with 4.5V DC supply
5. Set oscilloscope to 2V/Div and at 100ms/Div, vertical and horizontal sensitivity respectively
6. Connect oscilloscope probes against capacitor's leg (black probe is at negative terminal of the battery)

7. Momentary change position of switch SW_1 from P_2 to P_1 (charging processes)
8. Again change position of switch SW_1 from P_1 to P_2 (discharging processes)

As measured from oscilloscope, maximum voltage is 4.5V (when capacitor is full charged) and minimum voltage is 0V (when capacitor is completely discharged). The discharging provides the same kind of changing capacitor voltage, except this time the voltage jumps to full battery voltage when the switch is at position P_1 and slowly falls when the switch is at position P_2. You can make experiment again with different combinations of resistors and capacitors, making sure as always that the capacitor's polarity is correct.

5. 2. 1. Capacitor Code Information

Capacitor Code is designed to provide the value of alphanumeric coded ceramic, mylar and mica capacitors in general. They come in many sizes, shapes, values and ratings; many different manufacturers worldwide produce them and not all play by the same rules. Most capacitors actually have the numeric values stamped on them, however, some are color coded and some have alphanumeric codes. The capacitor's first and second significant number IDs are the first and second values, followed by the multiplier number code, followed by the percentage tolerance letter code. Usually the first two digits of the code represent the significant part of the value, while the third digit, called the multiplier, corresponds to the number of zeros to be added to the first two digits.

5. 2. 3. Determining Capacitor Values

The value of the capacitance in a capacitor can be determined by reading the prints in the capacitor. Often, high-capacitance capacitors, like electrolytic capacitors, have their values written explicitly in their casing; for example, 22 (Twenty two microfarads).

For smaller-valued capacitors like ceramic, mylar and mica capacitors have codes printed on them and not their actual value. This is because they usually come in very small sizes. The code is usually a two-digit or three-digit code. The two-digit code plainly represents the capacitance value in picofarads (pF). For example, a ceramic capacitor that has "22" printed on it would simply mean that it has a capacitance of 22. For the three-digit code, the first two digits are the significant digits and the third digit is the multiplier. As with the two-digit code, we read the values in the three-digit code in. For example, a ceramic capacitor that is printed with "102" has a capacitance of 10 x 100 or 1,000 or 0.001 and a ceramic capacitor that is printed with 223 has a capacitance of 22 x 1000 or 22,000 or 0.022. It must be noted that the digits "6" and "7" are not used in the code.

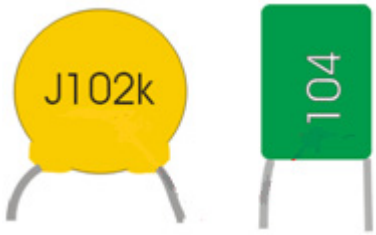


Figure 5-26: Example of capacitors with codes

Sometimes the code comes with a letter following the digits, say 102K. This letter represents the tolerance in the capacitance rating of the capacitor. This implies that the 102K capacitor has a capacitance of 1,000 . That is capacitance ranging from 900 to 1100.

The table 5-10 gives applicable values and letters used to represent tolerance on a capacitor.

Third digit	Multiplier or number of zeros	Letter	Tolerance
0	1	D	+/-0.5%
1	10	F	+/- 1%
2	100	G	+/- 2%
3	1000	H	+/- 3%
4	10000	J	+/- 5%
5	100000	K	+/- 10%
		M	+/- 20%
		P	+/- 100%
8	0.01	Z	+/- 80%
9	0.1		

Table 5-10: Applicable values and letters used to represent tolerance on capacitor

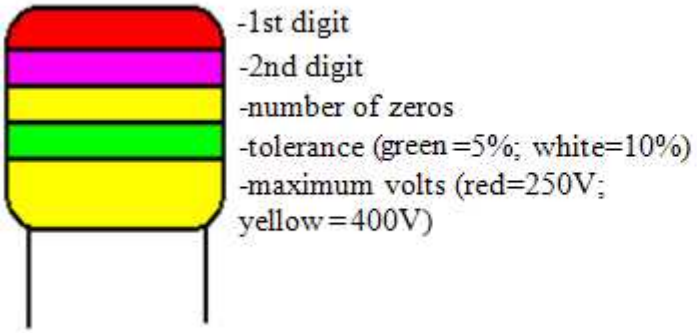
5. 2. 4. Capacitor color code

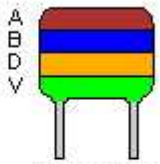
The way of identifying capacitor values and tolerances, an international color coding scheme was developed. This consists of colored bands in spectral order. The color codes currently in use are the Joint Army-Navy (JAN) code and the Radio Manufacturer's Association (RMA) code.

Color	Digit A	Digit B	Multiplier D	Tolerance (T)> 10pF	Tolerance (T)< 10pF	Temperature Coefficient (TC)
Black	0	0	x1	± 20%	± 2.0pF	
Brown	1	1	x10	± 1%	± 0.1pF	$-33x10^{-6}$
Red	2	2	x100	± 2%	± 0.25pF	$-75x10^{-6}$
Orange	3	3	x1,000	± 3%		$-150x10^{-6}$
Yellow	4	4	x10,000	± 4%		$-220x10^{-6}$
Green	5	5	x100,000	± 5%	± 0.5pF	$-330x10^{-6}$
Blue	6	6	x1,000,000			$-470x10^{-6}$
Violet	7	7				$-750x10^{-6}$
Grey	8	8	x0.01	+80%,-20%		
White	9	9	x0.1	± 10%	± 1.0pF	
Gold			x0.1	± 5%		
Silver			x0.01	± 10%		

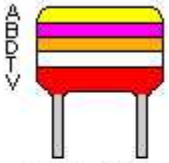
Table 5-11: Capacitor color codes

Examples:





10nF, 20%
100V



47nF, 10%
240V

5. 2. 5. Standard capacitor values

Capacitors are manufactured with respect to the standard values. Values other than from capacitor standard values are obtained by gouping capacitors either in series or in parallel. The table 5-12 shows capacitor standard values with ±10% tolerance.

Capacitor standard values (±10%)						
10pF	100pF	1000pF	0.010µF	0.10µF	1µF	10µF
12pF	120pF	1200pF	0.012µF	0.12µF	1.2µF	
15pF	15pF	1500pF	0.015µF	0.15µF	1.5µF	
18pF	18pF	1800pF	0.018µF	0.18µF	1.8µF	
22pF	22pF	2200pF	0.022µF	0.22µF	2.2µF	22µF
27pF	27pF	2700pF	0.027µF	0.27µF	2.7µF	
33pF	33pF	3300pF	0.033µF	0.33µF	3.3µF	33µF
39pF	39pF	3900pF	0.039µF	0.39µF	3.9µF	
47pF	47pF	4700pF	0.047µF	0.47µF	4.7µF	47µF
56pF	56pF	5600pF	0.056µF	0.56µF	5.6µF	
68pF	68pF	6800pF	0.068µF	0.68µF	6.8µF	
82pF	82pF	8200pF	0.082µF	0.82µF	8.2µF	

Table 5-12: Standard Capacitor values of ±10% tolerance

5. 2. 6. Capacitor grouping

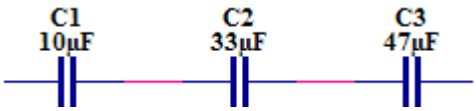
In a circuit two or more capacitors can be combined to obtain the desired capacitance value. When combining capacitors in a series connection, the capacitance is decreased, while in a parallel connection the capacitance is increased. This is the opposite of what happens when we combine resistors.

5. 2. 6. 1. Capacitors in series

In a series connection, the total capacitance is equal to the reciprocal of the sum of the reciprocal values of the capacitors. $1/C_t = 1/C_1 + 1/C_2 + 1/C_n$

Example: C_1 = 10uF; C_2 = 33uF and C_3 = 47uF

The circuit diagram:



Resolution:

$1/C_t = 1/10uF + 1/33uF + 1/47uF$

$1/C_t = 0.15157963uF$

$C_t = 6.597uF$

Series capacitors store the same amount of charge ($Q_T=Q_1=Q_2=Q_3=Q_n$) and the voltage across each one depends on its capacitance value (V=Q/C). The sum of the capacitor voltages (V_{C1}, V_{C2},V_{C3},... V_{Cn}) equal the source voltage Vs. Vs= $V_{C1}+V_{C2}+V_{C3}+... +V_{Cn}$

5. 2. 6. 2. Capacitors in parallel

In a parallel connection, the total capacitance is obtained by adding the individual capacitance values of the connected capacitors.

$$Ct = C_1 + C_2 + C_n$$

Example: C_1 = 10uF; C_2 = 33uF and C_3 = 47uF

The circuit diagram

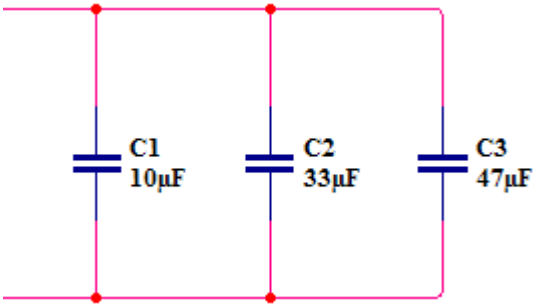


Figure 5-27: Example of a circuit with three parallel capacitors

Each capacitor in a parallel circuit stores a portion of the total charge and depends on its capacitance value (Q=CV). The total charge stored is given by: $Q_T=Q_1+Q_2+Q_3+...+Q_n$; Since the voltage across both capacitor is the same, the larger capacitor stores more charge

Solution:

$C_t = C_t = C_1 + C_2 + C_n = 10uF + 33uF + 47uF$

$C_t = 90uF$

5. 2. 7. Capacitor voltage rating

The voltage rating on a capacitor is the maximum amount of voltage that a capacitor can safely be exposed to and can store.

Below is the table describing the common capacitor working voltages.

Common Capacitor Working Voltages (DC), By Capacitor Type				
Ceramic	**Electrolytic**	**Tantalum**	**Mylar (Polyester)**	**Mylar (Metal Film)**
	10V	10V		
16V	16V	16V		
		20V		
25V	25V	25V		
	35V	35V		
50V	50V	50V	50V	
	63V			
100V	100V		100V	
	160V			
			200V	
	250V			250V
	350V			
			400V	400V
	450V			
600V				
				630V
1000V				

Table 5-13: Common capacitor working voltages

5. 2. 8. Testing the Capacitor

In practice, capacitor can get wrong and give worst response than expected. It is better to test the capacitor before using it. Here below are the possible tests that can be performed and the choice depends on the user preference.

- **Testing a Capacitor with ESR meter**

Experiment 5-8: Testing a Capacitor (ESR meter test)

Test a capacitor with an ESR meter (Equivalent Series Resistance) and determine its state.

Part lists

No	Items	Specifications	Quantity
1	Multimeter	Digital multimeter	1
2	Capacitor	Electrolytic capacitor	1

An ESR meter is a two-terminal electronic measuring instrument designed and used primarily to measure the equivalent series resistance (ESR) of real capacitors; usually without the need to disconnect the capacitor from the circuit it is connected to. Most ESR meters work by applying voltage pulses to the capacitor under test which are too short to appreciably charge it; any voltage

appearing across the capacitor is due to ohmic drop across the ESR.

Most ESR meters work by discharging a real electrolytic capacitor (essentially equivalent to a perfect capacitor in series with an unwanted resistance, the ESR) and passing an electric current through it for a short time, too short for it to charge appreciably. This will produce a voltage across the device equal to the product of the current and the ESR plus a negligible contribution from a small charge in the capacitor; this voltage is measured and its value divided by the current (i.e., the ESR) shown in ohms or milliohms on a digital display or by the position of a pointer on a scale. The process is repeated tens or hundreds of thousands of times a second

Figure 5-28: ESR meter

To test a capacitor for resistance using an ESR meter, follow the steps below.

Step 1- Remove power from the circuit.

Be certain the circuit is not connected to a power source and is dead.

Step 2- Discharge the capacitor.

Discharge the capacitor using a resistor with a resistance 5 to 50 times the rated voltage of the capacitor. Hold the resistor with insulated needle nose pliers and touch the resistor leads to the capacitor leads. Hold for several seconds to drain the capacitor into the resistor.

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Step 3- Test the capacitor with an ESR meter.

Connect the ESR meter probes to the capacitor using the correct polarity. The negative side of tube type capacitors is clearly marked with a " - " symbol (See photo of figure 5-29). Connect the black probe to the negative lead and the red probe to the positive lead.

Step 5- Review the test results.

Look at the readout on the ESR meter, which could be analog, LED readout, or digital. The reading is the equivalent series resistance which should be close to zero for a good capacitor. The higher the number, the more defective the capacitor. Remember, zero is ideal, but capacitors with age may climb higher than that.

Because of the process used for insulating pentoxide dielectric, the metallic (aluminium or tantalum) plate is always positive with respect to the electrolytic plate, and thus all electrolytic capacitors are polarized.

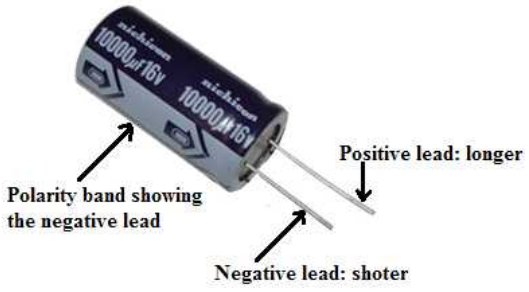

Figure 5-29: Capacitor polarity identification

- **Alternate Capacitor Test Method**

This method uses a common multimeter to test a capacitor. This test method is less accurate than the ESR test and requires at least one side of the capacitor to be removed from the circuit.

Step 1- Connect the meter to the capacitor

Connect your meter to the discharged leads of the capacitor. Be certain to connect the red probe to the positive capacitor lead, and the black probe to the negative lead.

Step 2- Watch the capacitor charge

For capacitors in the microfarad uF range or larger, you should be able to see the capacitor charge when connected to the meter. This is because the meter will charge the capacitor.

Step 3- Review the test results

When the meter is set in the high resistance range, the resistance should start out low and increase until it goes to open. If the capacitor is shorted, then it will never charge and resistance will not increase. If the capacitor is open, the resistance will be infinite immediately and will not change.

- **Test a Capacitor with Ohmmeter**

A very good test you can do is to check a capacitor with your multimeter set on the ohmmeter setting. This gives the value at which the settle on the state of capacitor is taken.

Experiment 5-9: Testing a Capacitor with digital Ohmmeter (digital multimeter)

By taking the capacitor's resistance, we can determine whether the capacitor is good or bad. To do this test, we take the ohmmeter and place the probes across the leads of the capacitor. The orientation doesn't matter, because resistance is not polarized.

Part lists

No	Items	Specifications	Quantity
1	Multimeter	Digital multimeter	1
2	Capacitor	Electrolytic capacitor	1

If the reading gives a very low resistance (near 0Ω) across the capacitor, we know the capacitor is defective. It is reading as if there is a short across it. If we read a very high resistance across the capacitor (several MΩ), this is a sign that the capacitor likely is defective as well. It is reading as if there is an open across the capacitor.

A normal capacitor would have a resistance reading up somewhere in between these 2 extremes, say, anywhere in the tens of thousands or hundreds of thousands of ohms. But not 0Ω or several MΩ.

This is a simple but effective method for finding out if a capacitor is defective or not.

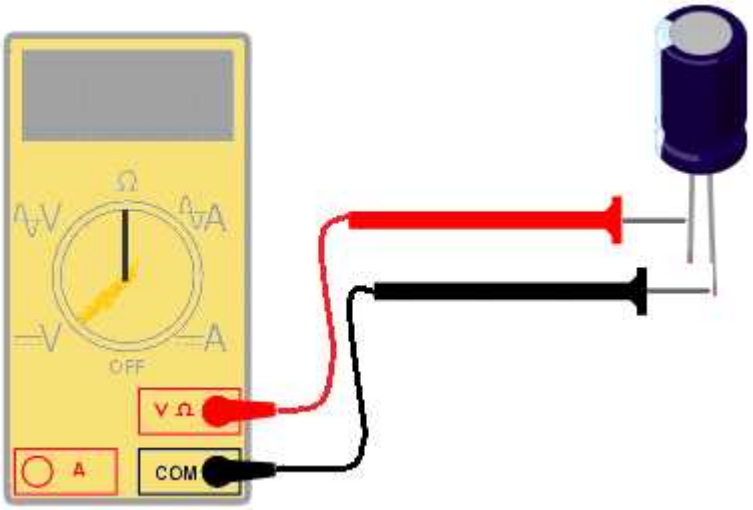

Figure 5-30: Test a capacitor with Ohmmeter

- **Testing Capacitors with an analog Ohmmeter (Analog Multitester)**

Unlike to the use of digital ohmmeter which gives a specific number, the use of analog ohmmeter to test capacitor gives the deflection of the pointer and its orientation helps to determine the state of capacitor.

Experiment 5-10: Testing Capacitors with an analog Ohmmeter (Analog Multitester)

A capacitor may develop troubles like open, shorted and weak or leaky. Following are rules to be followed in testing capacitors:

Part list

No	Items	Specifications	Quantity
1	Multimeter	Analog multimeter	1
2	Capacitor	Electrolytic capacitor	1

Steps

1. Switch off the power supply.
2. To be safe and to protect your ohmmeter from damage, discharge the capacitor before testing. Do this by short-circuiting its two terminals with a conductor. Make sure that the conductor that you are using has an insulated handle to protect you from electric shock.
3. Disconnect one terminal lead of the capacitor from the circuit before testing.
4. Adjust your ohmmeter to appropriate range. Use the guide below in selecting the range to be used for a range of capacitance values.

No	Capacitance			Range
1	0.01 uF	to	1 uF	X 10KΩ and above
2	1 uF	to	47 uF	X 1KΩ

3	47 uF to 1000 uF	X 10Ω
4	1000 uF and above	X 1Ω

Table 5-14: Ohm's range used to test a given capacitor

Connect the test probes to the terminal of the capacitor.

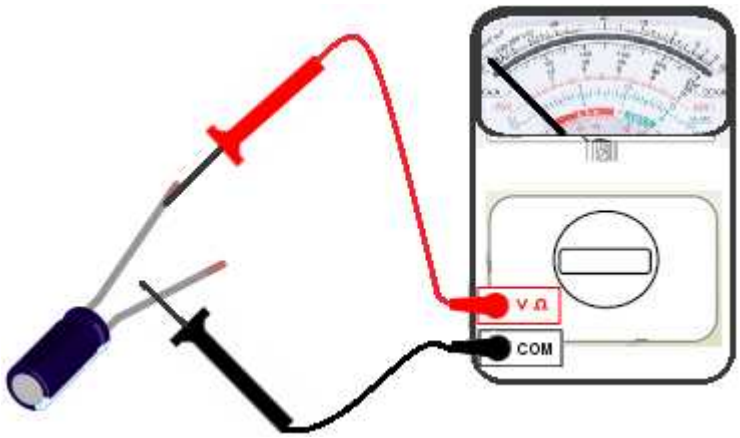

Figure 5-31: Test probes of analog ohmmeter connected to the terminals of the capacitor

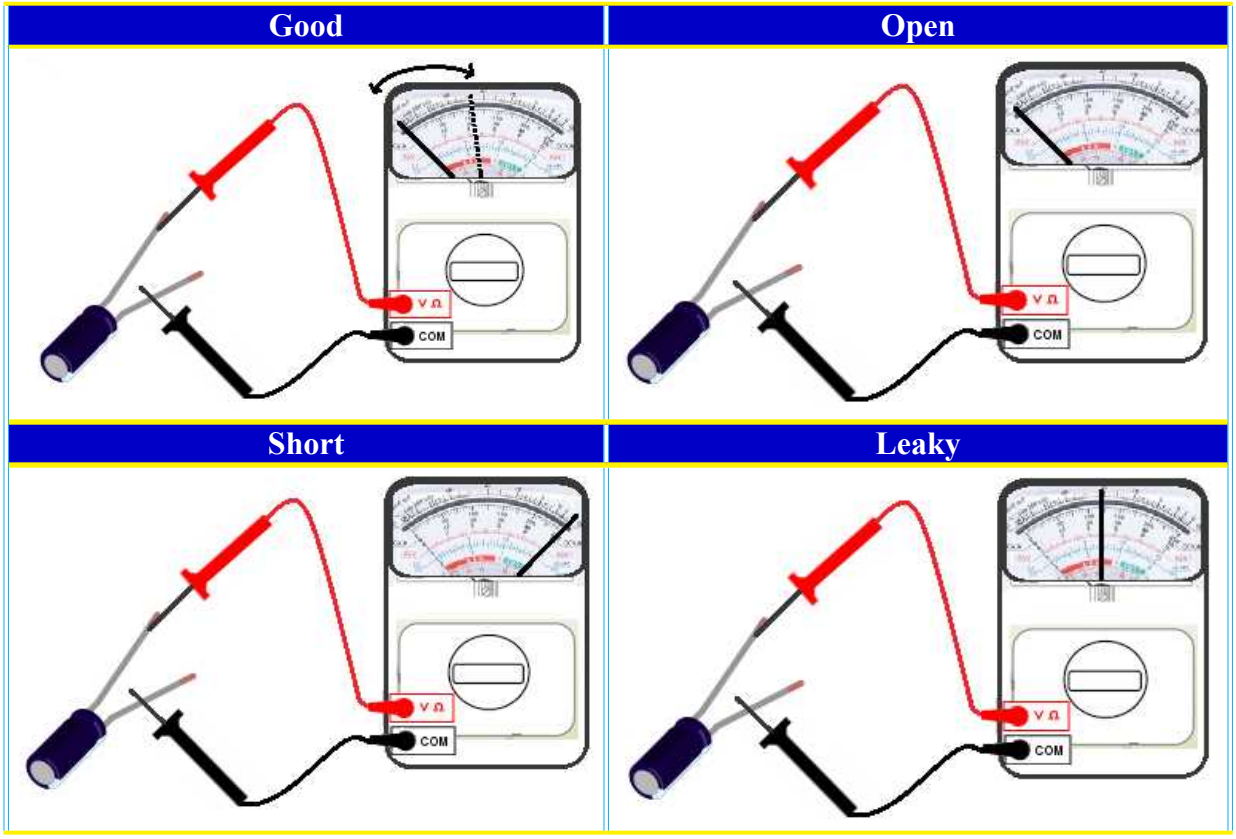

Figure 5-32: Four methods to identify capacitor's condition using analogue Ohmmeter

- **Test a Capacitor with a Multimeter in the Capacitance Setting**

Some digital multimeters are equipped with capacitance check range. If you have a capacitance meter on your multimeter, you can check the capacitance of the capacitor with a multimeter the same way as to measure resistor.

Experiment 5-11: Test a Capacitor with a Multimeter in the Capacitance Setting

All you have to do is to read the capacitance that is on the exterior of the capacitor and take the multimeter probes and place them on the leads of the capacitor. Polarity doesn't matter. This is the same as how the setup is for the first illustration, only now the multimeter is set to the capacitance setting.

You should read a value near the capacitance rating of the capacitor. Due to tolerance and the fact that (specifically, electrolytic capacitors) may dry up, you may read a little less in value than the capacitance of the rating. This is fine. If it is a little lower, it is still a good capacitor. However, if you read a significantly lower capacitance or none at all, this is a sure sign that the capacitor is defective and needs to be replaced.

Checking the capacitance of a capacitor is a great test for determining whether a capacitor is good or not

- **Test a Capacitor with a Voltmeter**

Capacitors are electronic storage devices for DC current. They store a potential difference of charges across their plate, which are voltages. The anode has a positive voltage and the cathode has a negative voltage.

Experiment 5-12: Test a Capacitor with a Voltmeter

Part lists

No	Items	Specifications	Quantity
1	Voltmeter	Digital multimeter	1
2	Capacitor	Electrolytic capacitor	1
3	Battery	9V dc supply	1

A test that you can do is to see if a capacitor is working as normal is to charge it up with a voltage and then read the voltage across the terminals. If it reads the voltage that you charged it to, then the capacitor is doing its job and can retain voltage across its terminals. If it is not charging up and reading voltage, this is a sign the capacitor is defective.

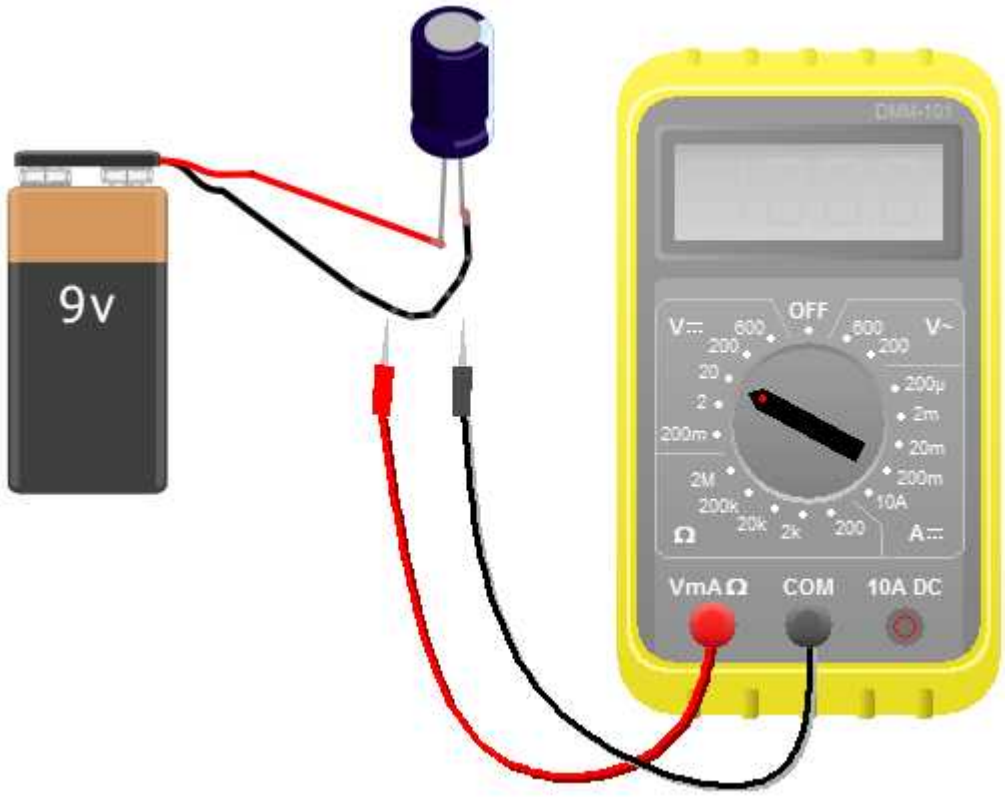

Figure 5-33: Test a Capacitor with a Voltmeter

Safety point

- **Capacitors are capable of storing electrical charge for a long time after power has turned off in a circuit. Be caraful when touching or handling capacitors in or out of a circuit. If you touch the leads, you may be in for a shock as the capacitor discharges through your body! It is usually good practice to discharge a capacitor using a shorting tool with an insulated grip of some sort before handling the capacitor.**
- **Be extremely careful with electrolytic capacitors because it does make a difference which way an electrolytic capacitor is connected. If a polarized capacitor is connected backwards, it may explode and cause injury.**

5. 2. 9. Capacitor in AC circuits

Capacitor blocks constant dc. A capacitor passes ac with an amount of opposition, called capacitance reactance, which depends on the frequency of the ac.

Capacitance reactance, Xc

From the circuits of figure 5-34, a capacitor is shown connected to a sinusoidal voltage source. When the source voltage is held at a constant amplitude value and its frequency is increased, the amplitude of the current increases. Also, when the frequency of the source is decreased, the current amplitude decreases.

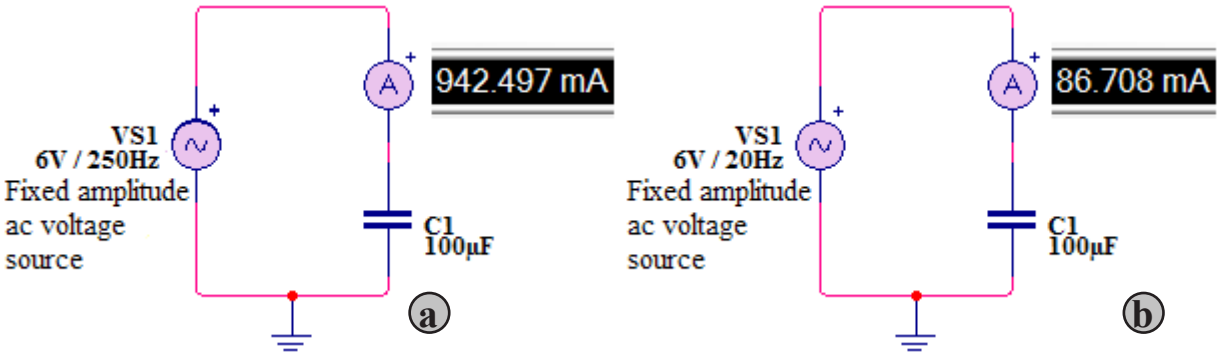

Figure 5-34: The current in a capacitive circuit varies directly with the frequency of the source voltage; (a) Current increases when the frequency increases, (b) Current decreases when the frequency decreases

Hands on tip

Some multimeters have a relatively low frequency response of 1KHz or less, while others can measure voltages or currents with frequencies up to about 2MHz. Always check to make sure that your meter is capable of making accurate measurements at the particular frequency you are working with.

Procedure

1. Connect a 220nF (no polarized) capacitor in series with ammeter and signal generator as shown in the circuit figure 3-35.
2. Set multimeter in amp's range 1A or 2A scale if provided.
3. Set the function generator to output a 6V rms sine wave with adjustable frequency.

Figure 5-35: Turn the knob in clockwise (a) to increase frequency, Turn the knob in anticlockwise (b) to decrease the frequency

4. Change the frequency by using the knob as shown; by at first turning in clockwise the knob (a), with this by increasing the frequency and at the second turning the knob in anticlockwise to decrease the frequency (b) all of these by observing the ammeter reading.
5. As frequency increases, the current increases to around 1A and when the frequency decreases the current decreases to around 0A

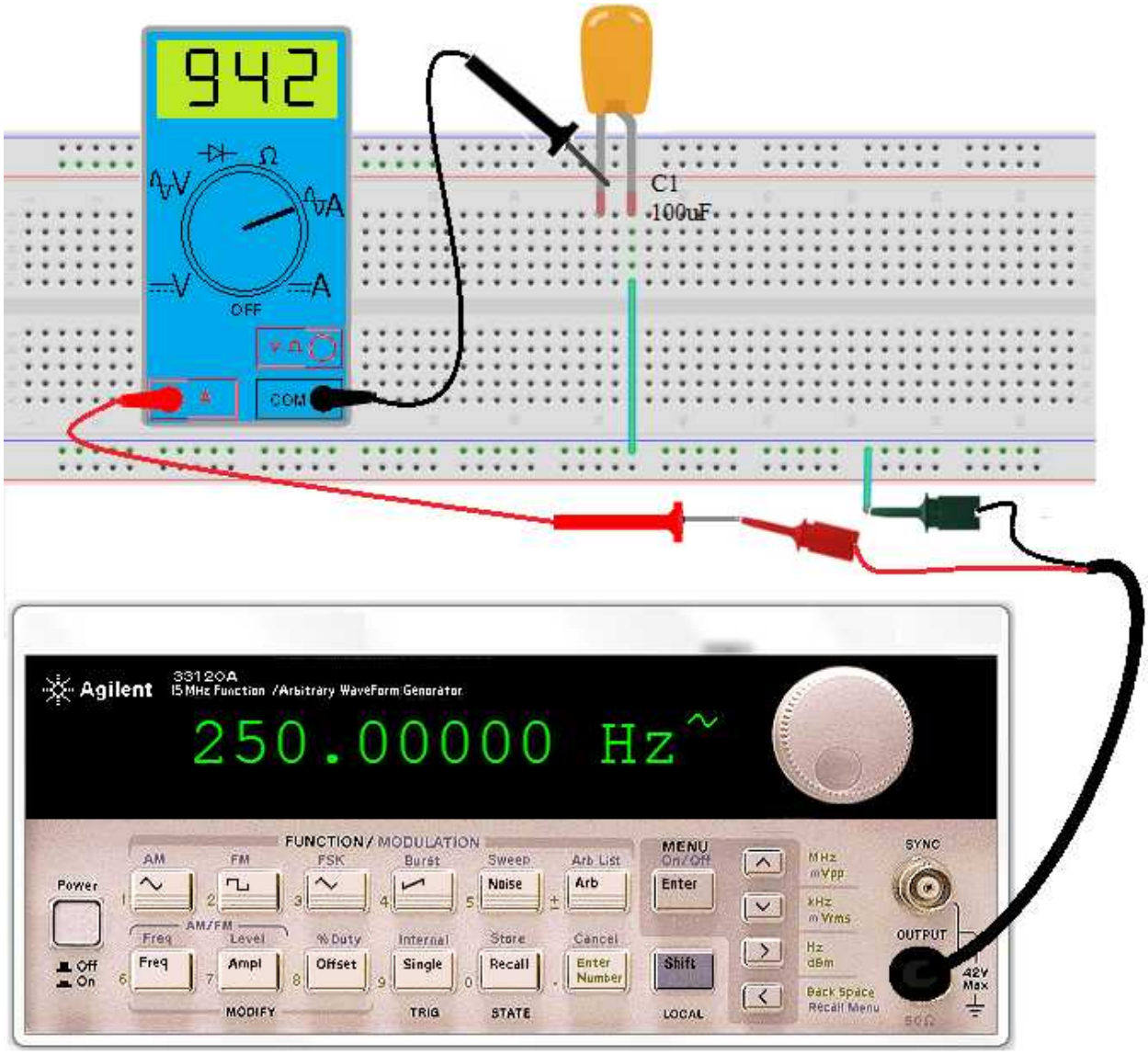

Figure 5-36: The current in a capacitive circuit varies directly with the frequency of the source voltage, real world circuit connection

When the frequency of the voltage increases, its rate of change also increases. This relationship is illustrated in figure 5-34 where the frequency is increased. Now, if the rate of which the voltage is changing increases, the amount of charge moving through the circuit in given period of time must also increase. More change in a given period of time means more current. For example, a tenfold increase in frequency means that the capacitor is charging and discharging 10 times as much in a given time interval. The rate of charge movement has increased 10 times. This means the current has increased by 10 because I=Q/t.

An increase in the amount of current with a fixed amount of voltage indicates that opposition to the current has decreased. Therefore, the capacitor offers opposition to current, and that opposition varies inversely with frequency.

The opposition to sinusoidal current in a capacitor is called capacitive reactance

The symbol of capacitive reactance is Xc, and its unit is the Ohm (Ω).

You have just seen that the frequency affects the opposition to current (capacitive reactance) in a capacitor. Now let's see how the capacitance (C) itself affects the reactance. Figure 5-37 in part (a) shows that when a sinusoidal voltage with a fixed amplitude and a fixed frequency is equal to 1uF capacitor, there is a certain amount of alternating current. When the capacitance value is increased to 2uF, the current increases, as shown in figure 5-37 part (b). Thus, when the capacitance is increased, the opposition to current (capacitive reactance) decreases. Therefore, not only is the capacitive reactance inversely proportional to frequency, but it is also inversely proportional to capacitance. This relationship can be stated as follows:

Xc is proportional to 1/*f*C.

It can be proven that the constant of proportionality that relates Xc to 1/*f*C is 1/2π. Therefore, the formula for capacitive reactance (Xc) is

$$Xc=1/2\pi fC$$

Xc is in Ohms where *f* is in hertz and C is in farads. The 2π term comes from the fact that, as you learned, a sine wave can be described in terms of rational motion, and one revolution contains 2π radians.

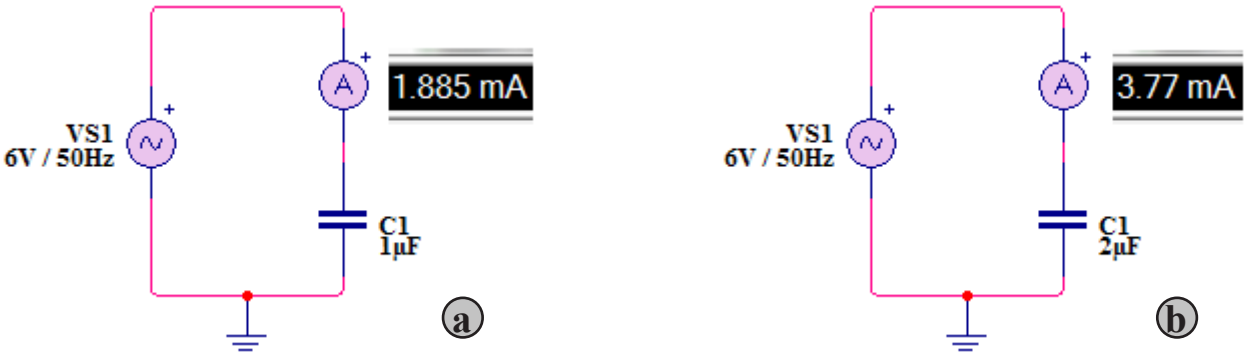

Figure 5-37: For a fixed voltage and fixed frequency, the current varies directly with the capacitance value; (a) Less capacitance, less current; (b) More capacitance, more current

Procedure

1. Connect the circuit as shown in figure 5-38
2. Set multimeter in amp's range 20mA scale
3. Set function generator to produce 6VAC at 50Hz
4. Connect the neutral of the function generator to ground bus of the breadboard (3) and by using jumper wires, the three leads of the capacitor C_1, C_2 and C_3 are interconnected to ground

5. Connect the multimeter's red lead to the line output of function generator and the black lead of the multimeter to the lead of the capacitor C_1 (2) and then observe the ammeter reading. The ammeter reading is about 1.88mA.
6. Move the black lead of multimeter to the leads of capacitor C_2 parallel to C_3 (2) and again observe the ammeter reading. The ammeter reading is about the twice the previous reading.

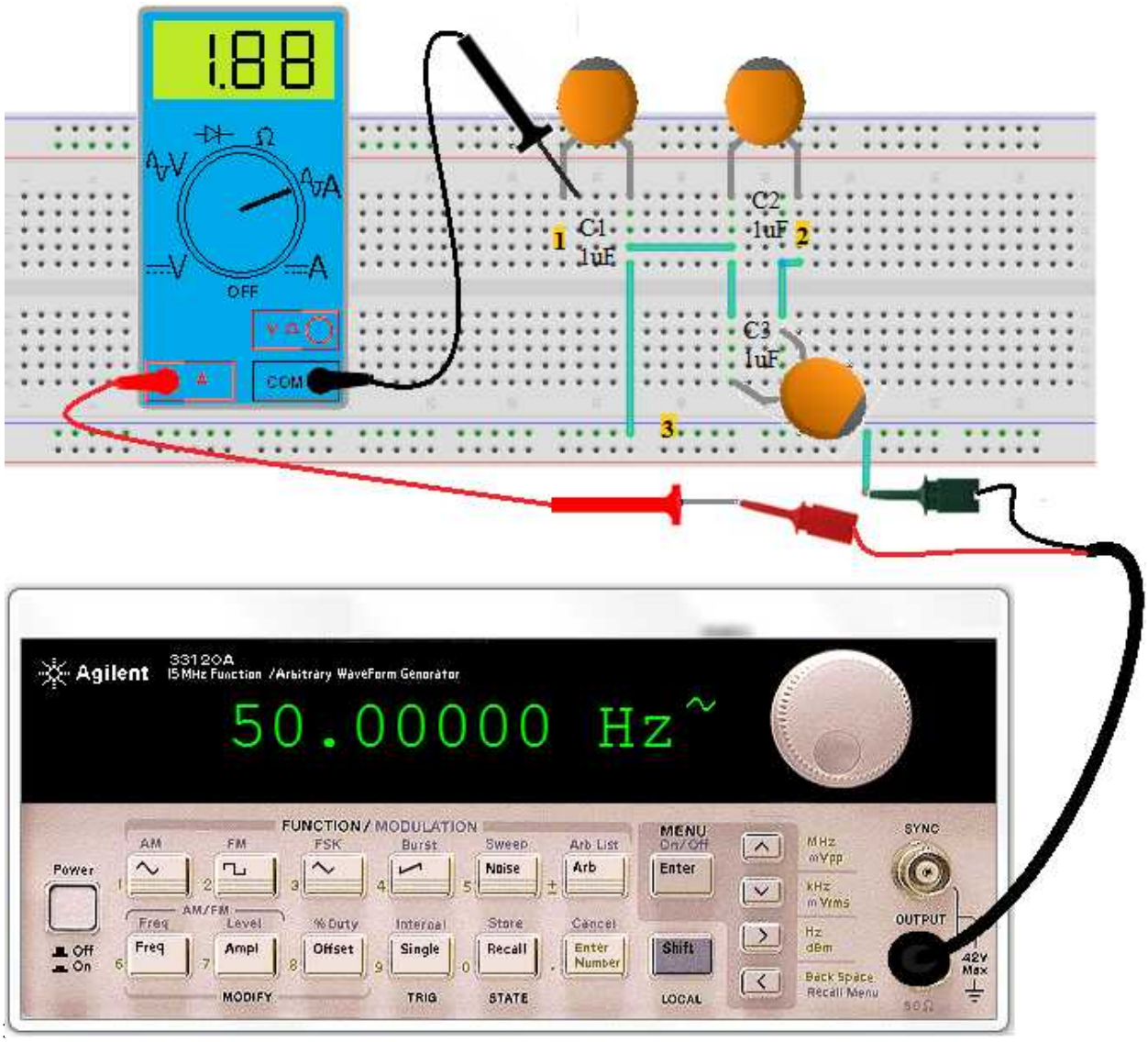

Figure 5-38: For a fixed voltage and fixed frequency, the current varies directly with the capacitance value real world circuit connection

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5. 2. 10. Variable capacitors

Variable capacitors are used in a circuit when there is a need to adjust the capacitance value either manually or automatically. These capacitors are generally less than 300 pF but are available in larger values for specialized applications. The schematic symbol for a variable capacitor is shown in figure 5-39.

Adjustable capacitors that normally have sloted screw-type adjustments and are used for very fine adjustments in a circuit are called *trimmers*. Ceramic or mica is a common dielectric in these types of capacitors, and the capacitance usually is changed by adjusting the plate separation.

Figure 5-39: Symbol of variable capacitor

The capacitance of a capacitor is analogous to the resistance of a resistor. In fact, both are expressed in Ohms. Since both *R* and *Xc* are forms of opposition to current, Ohm's law applies to capacitive circuits as well as to resistive circuits.

$$I = V/Xc$$

Hands on tip

Chip capacitors are for surface mounting on a printed circuit board and have a conductive terminals plated on the ends. These capacitors will withstand the molten solder temperatures encountered in reflow and wave soldering used in automated circuit board assembly. Chip capacitors are in great demande because of the move toward miniaturization.

Application of Capacitors

- **Electrolyte capacitors:** Used as filter in a power supply, time constant circuits, bypass, coupling/decoupling, smoothing and power electronic applications.
- **Non-polarised electrolytic capacitors**: Used in applications such as AC motor starting, cross over networks and large pulse signals.
- **Ceramic capacitors**: Used as bypass capacitor and used in decoupling applications, frequency discriminators and biasing applications.
- **Tubular capacitor:** Used to isolate the antennas in receivers.
- **Polystyrene capacitors:** Used in coupling, resonant and measuring circuits.
- **Polyester capacitors:** Used for coupling /decoupling applications, and also in power electronics.
- **Polycarbonate capacitors:** Used in dc applications.
- **Mica capacitors:** Used as coupling capacitors at high frequency, in radio transmitters, measuring circuits, bypass circuits and RF resonant circuits.
- **Variable capacitors:** Used in tuning circuits of communication receivers, transmitters and in oscillators.

5. 3. Inductor

An inductor or bobbin is a passive component of an electrical circuit, which stores energy in

magnetic field when the strength of current increase, and return energy when the strength of current decrease.

(1)

An inductor can be a single turn of wire or many turns:

(2)

(3)

An inductor can be wound:

On a plastic former (plastic spool) on a metal core or on air core

(4)

(5)

(6)

Figure 5-40: Inductor symbol (1), Single turn inductor (2), Many turns inductor (3), Inductor on plastic spool (4), Inductor on a meatal core (5), Inductor on air core (6)

An inductor can almost be any size or shape and is the most complex component in electronics. Inductance is measured in Henries. One Henry is a large unit. An inductor of 1 Henry would be a few cm in diameter and a few cm long and have many turns of wire on a ferrite core.

5. 3. 1. Inductor Color Codes

Inductors are labeled with a number of different ways. The most common are text codes and color codes. The color codes for inductors are identical to that of a resistor so if you are familiar with resistors this should be very easy. The tricky part is remembering the results from this will be in micro Henrys, not just Henrys.

- Values are in micro Henries (μH)

- First two digits are the value
- Third digit is the multiplier
- If there is an *R*, it acts as a decimal point, and there is no multiplier
- Examples:
  - 101 = 10*10^1µH = 100µH
  - 4R7 = 4.7µH
- Suffix
  - Sometimes the precision of the inductor will be marked, using a final letter F, G, J, K, or M
    - F = +/-1%
    - G = +/-2%
    - J = +/-5%
    - K = +/-10%
    - M = +/-20%

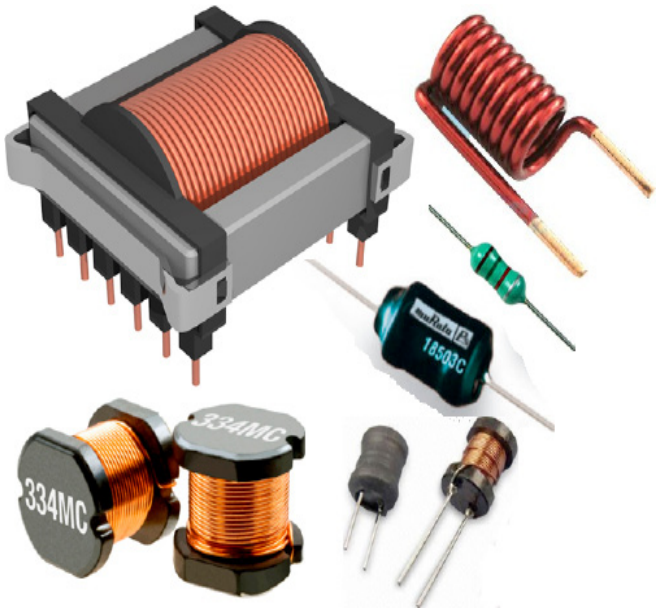


Figure 5-41: Different inductor shapes

Color Code Markings

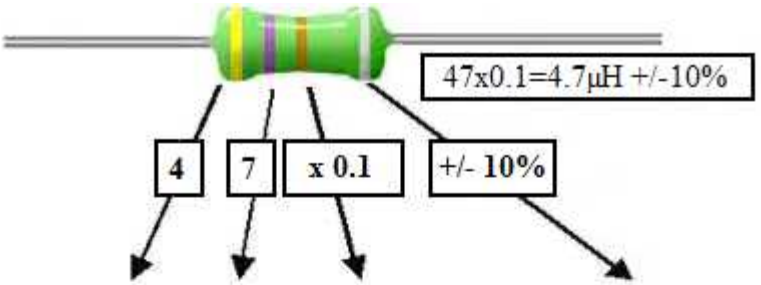
Inductors can be marked by colored bands or colored dots. Each color represents a value.

The color codes for inductors are identical to that of a resistor so if you are familiar with resistors this should be very easy. The tricky part is remembering the results from this will be in microHenrys, not just Henrys. From the inductor color code table, the last band is the tolerance, and the band right before tolerance band is the multiplier. The other bands are the numbers.

The military standard for cylindrical inductors specifies 5 coloured bands. The same colours are used as in the 4 band code, but:

For band 1, a double width sliver band is used to signify Military Standard.

- **Four Bands Standard EIA Colour Code for Inductors.**



Band	1	2	3	4
Meaning	1st Digit	2nd Digit	Multiplier (No. of zeros)	Tolerance %
Gold			x 0.1 (divide by 10)	+/-5%
Silver			x 0.01 (divide by 100)	+/-10%
Black	0	0	x1 (No Zeros)	+/-20%
Brown	1	1	x10 (0)	
Red	2	2	x100 (00)	
Orange	3	3	x1000 (000)	
Yellow	4	4	x10000 (0,000)	
Green	5	5		
Blue	6	6		
Violet	7	7		
Grey	8	8		
White	9	9		

Table 5-15: Four band inductor color codes

Note: If no Band 4 is used, tolerance is +/-20%

Example: Suppose we have the colors yellow, red, brown, black. They would mean the inductor has a value of: yellow - red - brown - black

4 2 x10 +/-20% So we have 42 * 10 +/-20%,

Meaning that the inductance is 420uH (micro-Henrys) with a 20 percent tolerance, or in other words, our actual inductance can be anywhere between 336µH and 504µH micro Henrys.

Notes: For values less than 10µH: Bands 2, 3 and 4 indicate the value of inductance in µH, a gold band might be used in either band 2 or band 3. In either of these two bands, gold indicates a decimal point and band 4 is used as a digit instead of a multiplier band. When no gold band is present in bands 2 or 3, band 4 is a multiplier band.

For example:

- If bands 2, 3 and 4 are red, gold, red the value would be 2.2 µH
- If bands 2, 3 and 4 are gold, yellow, violet the value would be 0.47 µH (470nH)

Band 5 indicates the tolerance between 1% and 20%

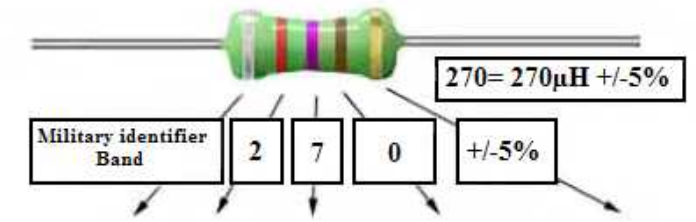
For values of 10µH or more:

Bands 2 and 3 represent basic value, and band 4 gives the number of zeros.

For example:

If bands 2, 3 and 4 are red, violet, orange the value would be 27000 µH

- **Five Band Military Standard Inductor Color Code**



Band	1	2	3	4	5
Meaning (See Notes)	Mil. Spec.	Digit or Dec. point	Digit or Dec. point	Digit (or Multiplier)	Tolerance %
Gold		Decimal point	Decimal point		+/-5%
Silver	Always Silver double width				+/-10%
Black		0	0	0 (or x 1)	+/-20%
Brown		1	1	1 (or x 10)	+/-1%
Red		2	2	2 (or x 100)	+/-2%
Orange		3	3	3 (or x 1,000)	+/-3%
Yellow		4	4	4 (or x 10,000)	+/-4%
Green		5	5	5	
Blue		6	6	6	
Violet		7	7	7	
Grey		8	8	8	
White		9	9	9	

Table 5-16: Five Band Military Standard Inductor Color Codes

Experiment 5-13: Coil rewinding and faraday's law

Faraday's Law of Induction

Faraday's Law of Induction states that any change in magnetic environment of a coil of wire will cause a voltage, electromotive force (emf), to be "induced" in the coil.

Make 50 turns on a cylindrical core using a 0.5 mm^2 copper wire isolated. Turns are made by rotating from left to right. Let consider the starting terminal as positive and the ending as negative. Connect both ends on the oscilloscope probes. The starting at the positive probe (red probe) and the ending terminal at the negative probe (black probe). Regulate the oscilloscope at low Verti-

cal sensitivity control of 10 mV/DIV. pass a permanent magnet closer to designed inductor and observe the voltage variation produced on oscilloscope.

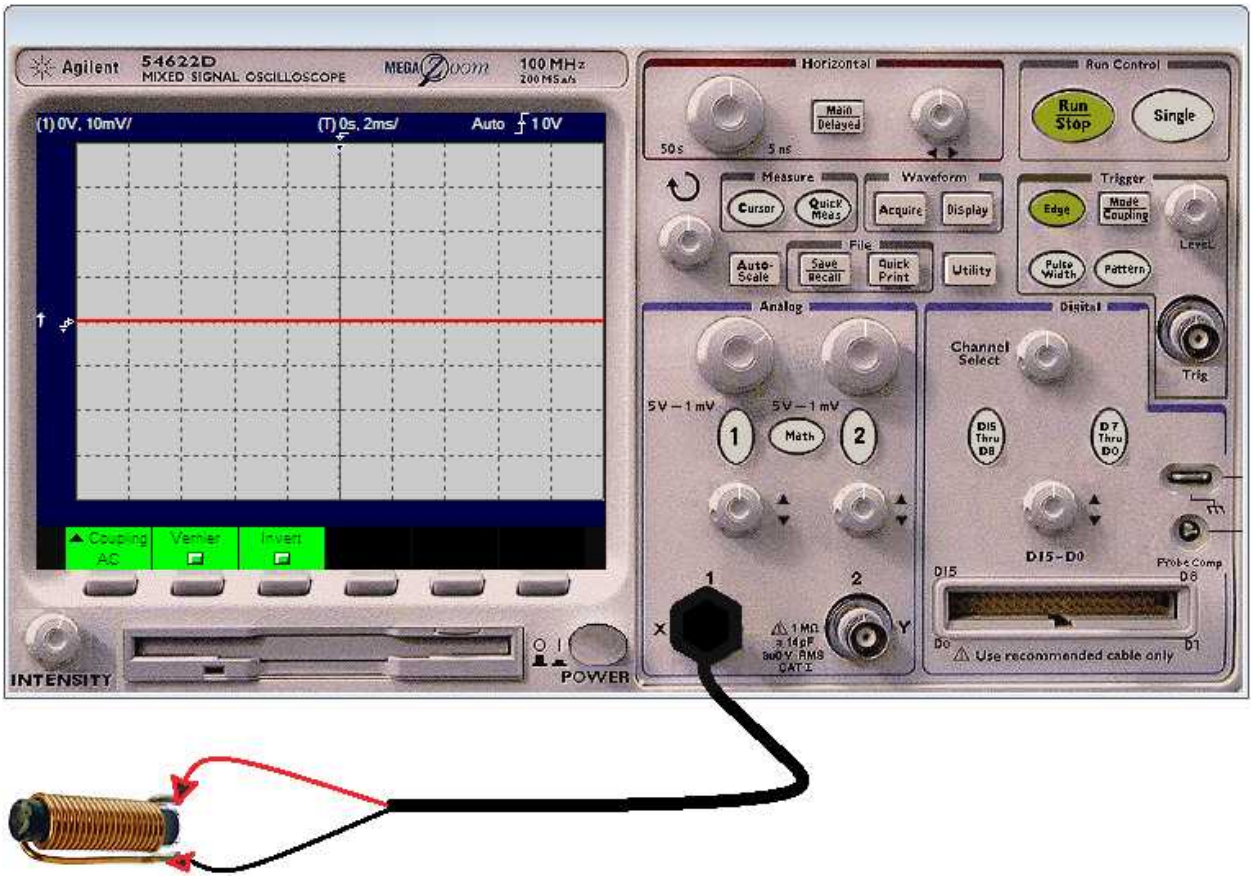


Figure 5-42: Inductor rewinding and voltage generation

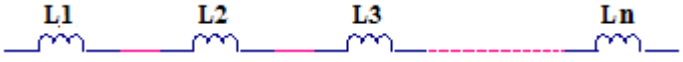
chap 5

5. 3. 2. Inductor grouping

Inductor can be grouped either in series or in parallel. When inductors are connected in series, the total inductance increases. When inductors are connected in parallel, the total inductance decreases.

- **Series inductors**

When inductors are connected in series, the total inductance, L_T, is the sum of the individual inductances. The formula for L_T is expressed in the following equation for the general case of *n* inductors in series

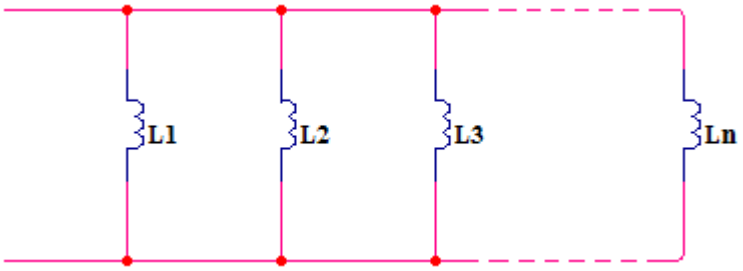


$$L_T = L_1 + L_2 + L_3 + \cdots L_n$$

Notice that the calculation of total inductance in series is analogous to the calculation of total resistance in series and total capacitance in parallel.

- **Parallel inductors**

When inductors are connected in parallel, the total inductance is less than the smallest inductance. The general formula states that the reciprocal of the total inductance is equal to the sum of the reciprocals of the individual inductances.



$$1/L_T = 1/L_1 + 1/L_2 + 1/L_3 + ... + 1/L_n$$

You can calculate total inductance, L_T, by taking the reciprocals of both sides of the previous equation.

$$L_T = 1/(1/L_1 + 1/L_2 + 1/L_3 + ... + 1/L_n)$$

Notice that this calculation of total inductance in parallel is analogous to the calculation of the total parallel resistance and total series capacitance.

5. 3. 3. Inductor in AC Circuits

Inductive reactance, XL

chap 5

An inductor passes ac but with an amount of opposition that depends on the frequency of the ac supply. In circuits of figure 5-43 an inductor is shown connected to a sinusoidal voltage source. When the source voltage is held at a constant amplitude value and its frequency is increased, the amplitude of the current decreases. Also, when the frequency of the source is decreased, the current amplitude increases.

Part list

No	Item	Quantity
1	Breadboard	1
2	1H inductor (Step-down power transformer (110-220V / 6 V))	1
3	6VAC source with different frequencies capability (function generator)	1
4	Wire (0.33mm^2 solid wire)	5cm
5	Ammeter (Digital multimeter set in amps range)	1

When the frequency of the source voltage increases, its rate of change also increases, as you already know. Now, if the frequency of the source voltage is increased, the frequency of the current also increases. According to the Faraday's and Lenz's Laws, this increase in frequency induces more voltage across the inductor in a direction to oppose the current and causes it to decrease in amplitude. Similarly, a decrease in frequency will cause an increase in current.

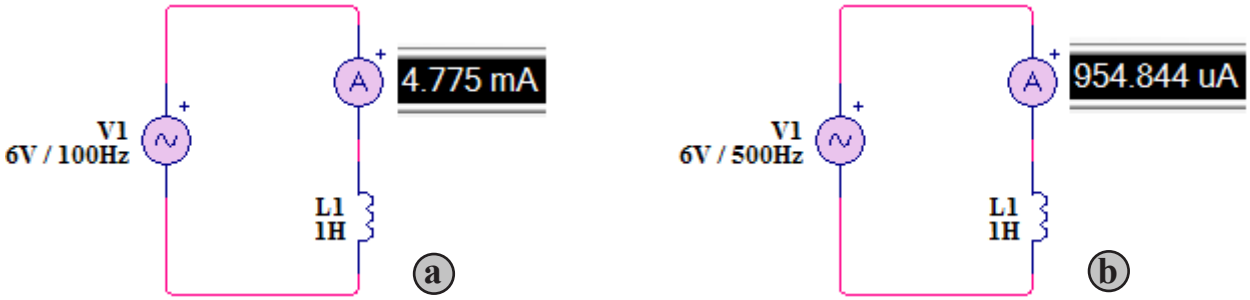


Figure 5-43: The current in an inductive circuit varies inversely with the frequency of the source voltage. (a) Current decreases when the frequency increases, (b) Current increases when the frequency decreases

A decrease in the amount of current with an increase in frequency for a fixed amount of voltage indicates that opposition to the current has increased. Thus, the inductor offers opposition to current, and that opposition varies directly with frequency.

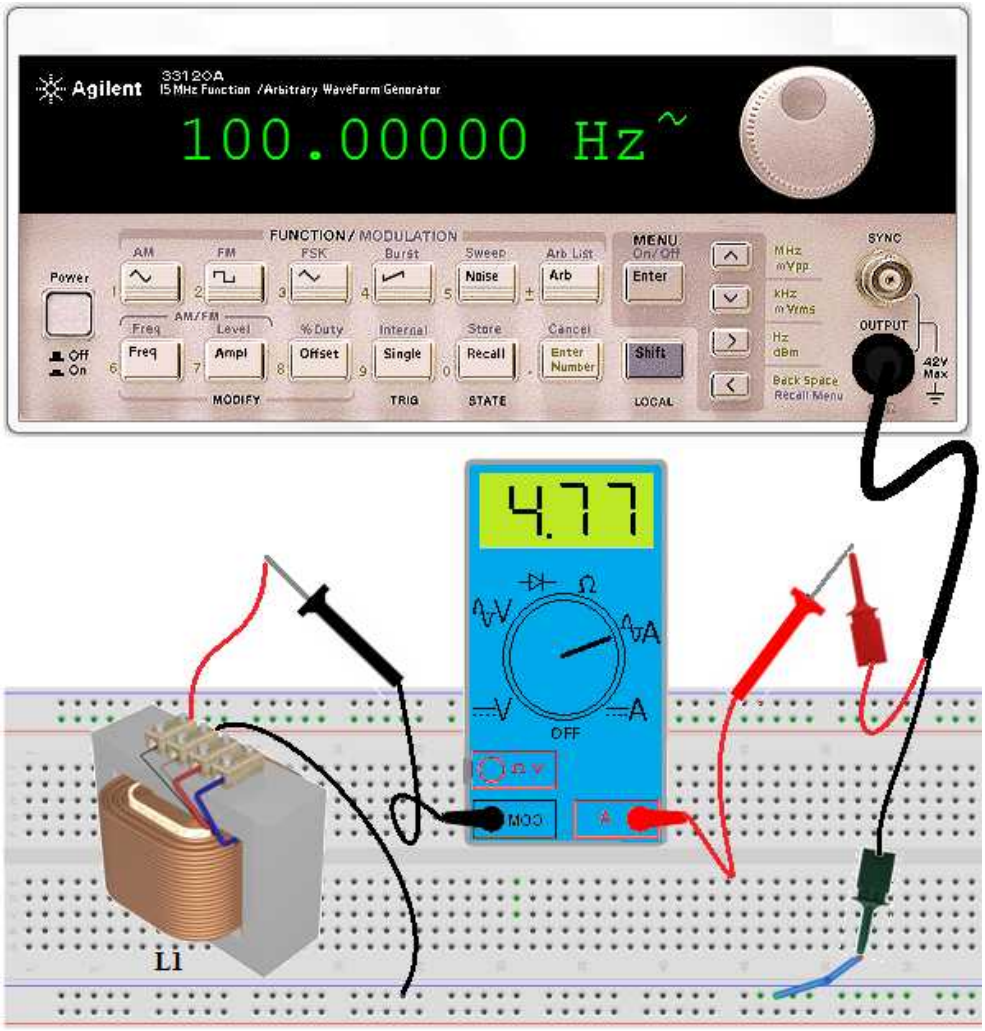


Figure 5-44: The current in an inductive circuit varies inversely with the frequency of the source voltage, circuit connection

Procedure

1. Preferably use power transformer as an inductor, with only one winding connected. The unused winding should be left open. A simple iron core, single-winding inductor may also be used, but such inductors are more difficult to obtain than power transformers and have a low internal resistance which can be neglected and cause damage to the ammeter. Power transformers have primary (110 volt) winding inductances of approximately 1H.
2. Connect the circuit as shown in figure 5-44 (make sure the ammeter is in series with the transformer's inductance)
3. Set multimeter in amp's range 200 mA scale
4. Set function generator to produce 6 VAC at first 100 Hz and adjust the frequency up to 500Hz with this by observing the current amplitude on ammeter

Inductive reactance is the opposition to sinusoidal current in an inductor

The symbol of inductive reactance is $X_{L,}$ and its unit is Ohm (Ω).

You have just seen how frequency affects the opposition to current (inductive reactance) in an inductor. Now, let's see how the inductance, L, affects the reactance. The figure 5-45 in part (a) shows that when a sinusoidal voltage with a fixed amplitude and fixed frequency is applied to a 1H inductor, there is a certain amount of alternating current. When the inductance value increased to 2H, the current decreases as shown in figure 5-45 part (b).

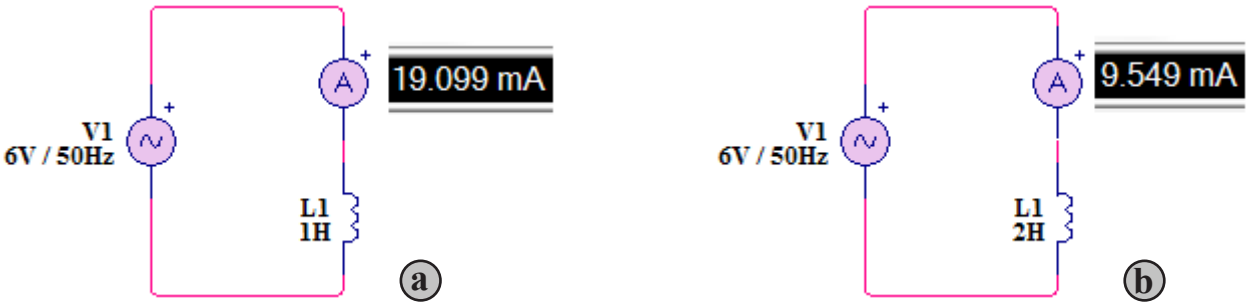


Figure 5-45: For a fixed voltage and fixed frequency, the current varies inversely with the inductance value. (a) Less inductance more current, (b) More inductance less current

Thus, when the inductance is increased, the opposition to current (inductive reactance) increases. So not only is the inductance reactance directly proportional to the frequency, but it is also directly proportional to inductance. This relationship can be stated as follows:

XL is proportional to fL

It can be proven that the constant of the proportionality is 2π, so the formula for inductive reactance (X_L) is

$$X_L = 2\pi f L$$

X_L is in Ohms when frequency f is in hertz and L is in henries. As with capacitive reactance, the 2π term comes from the relationship of the sine wave to rotational motion.

Procedure

1. Preferably use power transformer as an inductor, with only one winding having center tapped connected. The unused winding should be left open. Is possible to have the simple iron core, single-winding inductors may be used instead by making sure that they have a desired inductance and not negligible internal resistance as well. Once a power transformer is used, assume that the primary corresponding to 110 volt winding has inductances of approximately 1H while the primary of 220 Volt winding has inductances of approximately 2H.

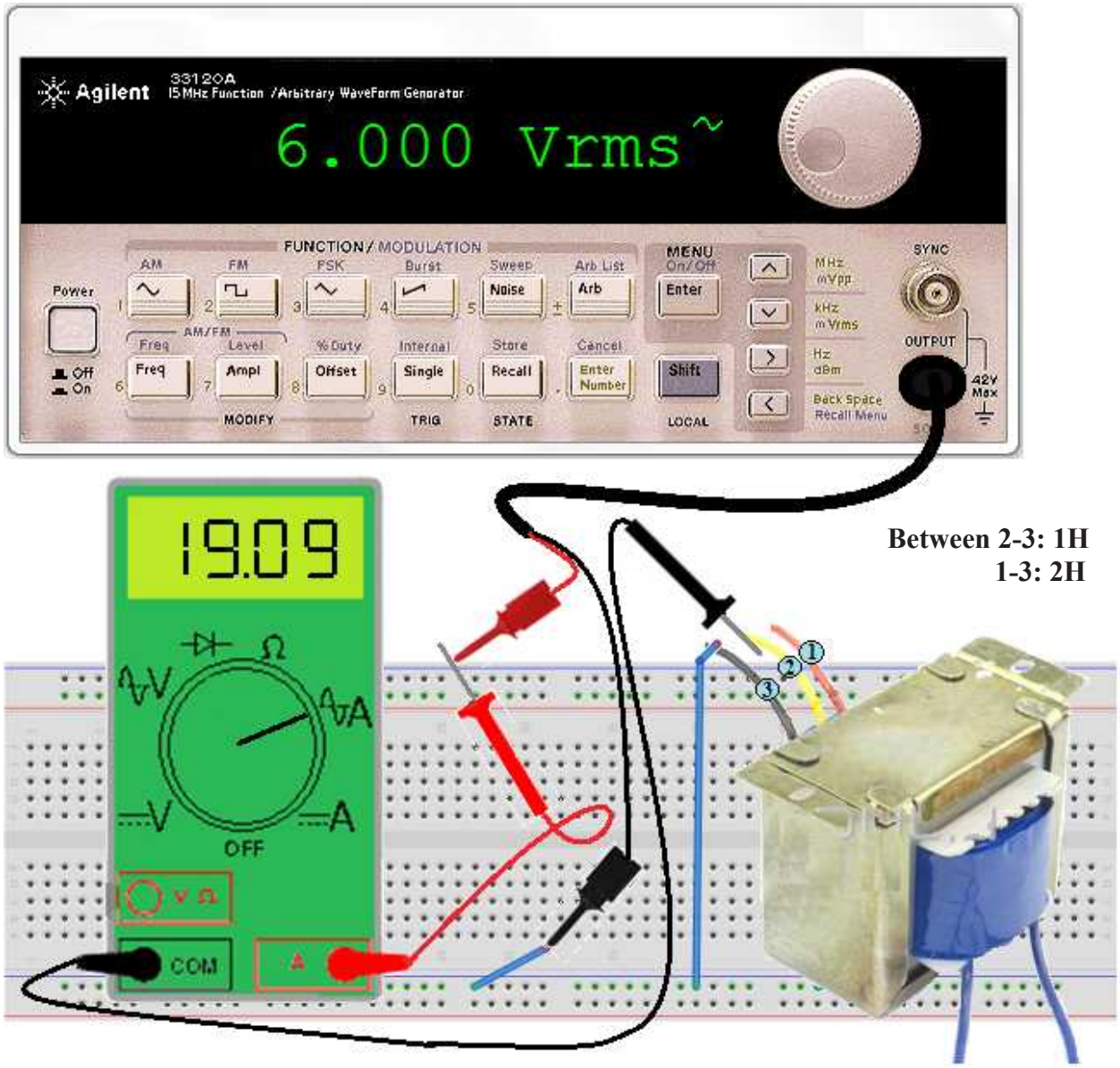


Figure 5-46: For a fixed voltage and fixed frequency, the current varies inversely with the inductance value, circuit connection

2. Connect the circuit as shown in figure 5-46 (make sure the ammeter is in series with the transformer's inductance)
3. Set multimeter in amp's range 200mA scale
4. Set function generator to produce 6VAC at 50Hz
5. Connect the neutral of the function generator to the third wire (3) of the transformer
6. Connect the multimeter's red lead to the line output of function generator and the black lead of the multimeter to the second wire (2) of the transformer and then observe the ammeter reading. The ammeter reading is about 19.099mA.
7. Move the black lead of ammeter to the first wire (1) of the transformer and again observe the ammeter reading. The ammeter reading is about 9.549mA.

Experiment 5-14: Tank circuit

Inductor-capacitor *tank* circuit

The parallel resonant LC circuit is often called a *tank circuit*. The term tank circuit refers to the fact that the parallel resonant circuit stores energy in the magnetic field of the coil and in the electric field of the capacitor. The stored energy is transferred back and forth between the capacitor and the coil on the alternate half-cycles as the current goes first one way and then the other when the inductor deenergizes and the capacitor charges, and vice versa.

Parts and materials

No	Item	Quantity
1	Oscilloscope	1
2	Non-polarized capacitor (10 µF)	2
3	Breadboard	1
4	Step-down power transformer (110-220V / 6 V)	1
5	6V battery	1
6	Wire (0.33mm^2 solid wire)	20cm

The power transformer is used simply as an inductor, with only one winding connected. The unused winding should be left open. A simple iron core, single-winding inductor (sometimes known as a choke) may also be used, but such inductors are more difficult to obtain than power transformers.

Procedure and working principle

If an inductor and a capacitor are connected in parallel with each other, and then briefly energized by connection to a DC voltage source, oscillations will result as energy is exchanged from the capacitor to inductor and vice versa. These oscillations may be viewed with an oscilloscope connected in parallel with the inductor/capacitor circuit. Parallel inductor/capacitor circuits are commonly known as tank circuits. A high voltage can be generated by the inductor when the battery is disconnected (inductive "kickback"). This high voltage of the short time has to be well managed to avoid any damage especially when using a PC/sound card as an oscilloscope for this

experiment will surely damage the sound card's input and perhaps other portions of the computer as well.

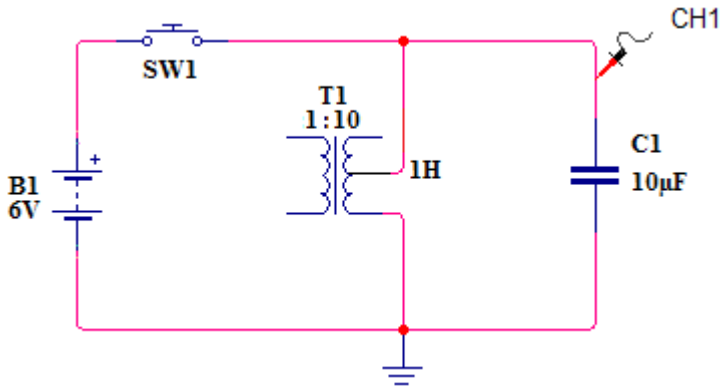


Figure 5-47: Tank circuit

A tank circuit's natural frequency, called the resonant frequency, is determined by the size of the inductor and the size of the capacitor, according to the following equation:

$$F_{resonance} = 1/(2\pi\sqrt{LC})$$

Many small power transformers have primary (110 volt) winding inductances of approximately 1H. Use this figure as a rough estimate of inductance for your circuit to calculate expected oscillation frequency.

Ideally, the oscillations produced by a tank circuit continue indefinitely. Realistically, oscillations will decay in amplitude over the course of several cycles due to the resistive and magnetic losses of the inductor. Inductors with a high "Q" rating will, of course, produce longer-lasting oscillations than low-Q inductors.

Try changing capacitor values and noting the effect on oscillation frequency. You might notice changes in the duration of oscillations as well, due to capacitor size. Since you know how to calculate resonant frequency from inductance and capacitance, you figure out a way to calculate inductor's inductance from known values of circuit capacitance (as measured by a capacitance meter) and resonant frequency (as measured by an oscilloscope).

While using computer simulation, resistance may be intentionally added to the circuit, either in series or parallel, for the express purpose of dampening oscillations. Eliminating this resistor from the circuit results in endless oscillation.

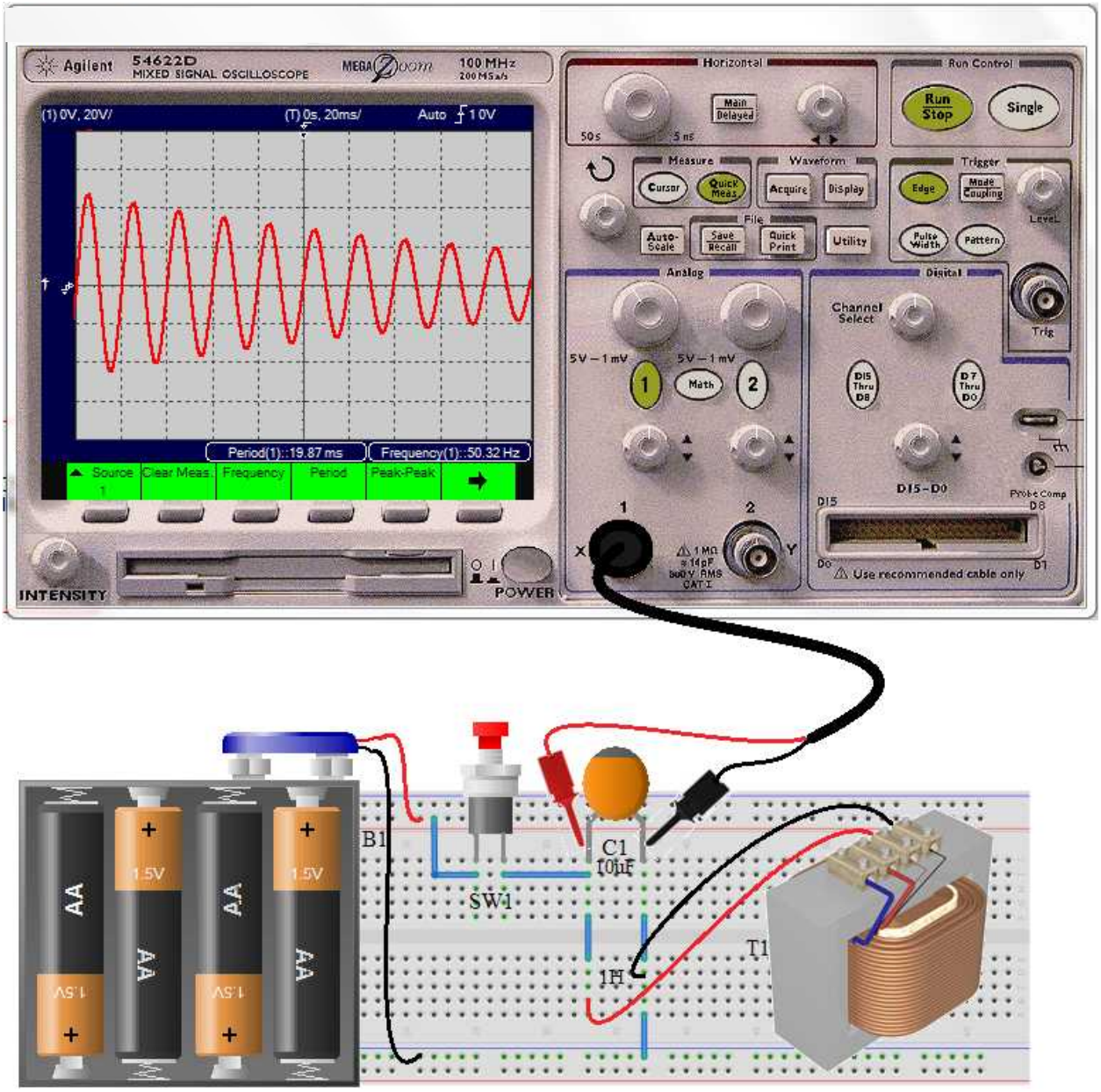


Figure 5-48: Tank circuit connection

RLC circuits

Resistor, Inductor and capacitor can be combined to make a single circuit called *RLC* circuit. These can be configured in series or in parallel depending on the desired application. One of the common use of series *RLC* circuits is in the filter applications.

Example of a filter: **The band-pass filter**

A band-pass filter allows signal at the resonant frequency and at the frequencies within a certain band (or rang) extending below and above the resonant value to pass from input to output without a significant reduction in amplitude. Signal at frequencies lying outside this specified band (called

the bandpass) are reduced in amplitude to below a certain level and are considered to be rejected by the filter.

The filtering action is the result of the impedance characteristic of the filter. The impedance is minimum at resonance and has increasingly higher value below and above the resonance frequency. At very low frequencies, the impedance is very high and tends to block the current. As the frequency increases, the impedance drops, allowing more current and thus more voltage across the output. At the resonance frequency, the impedance is very low and equal to the winding resistance of the coil. At this point there is a maximum current and the resulting output voltage is maximum. As the frequency goes above the resonance, the impedance again increases, causing the current and the resulting output voltage to drop.

Part list

No	Item	Quantity
1	Breadboard	1
2	Inductor 47mH	1
3	10VAC source with different frequencies capability (function generator)	1
4	Wire (0.33mm^2 solid wire)	20cm
5	Resistor 100Ω	1
6	Capacitor 220nF	

The circuits of figure 5-49 illustrate the general frequency response of a series resonant band-pass filter.

For above given resistor, capacitor and inductor let's determine band-pass filter related quantities.

Resonant frequency, f_r= =1/(2*3.14*√0.00022*0.047)=1565Hz

Inductive reactance, XL=2πLf=2*3.14*0.047H*1565Hz=461.63Ω

Quality factor Q of the circuit is the ratio of the reactance power in the inductor to the true power in the winding resistance of the coil and any other resistance in series with the coil.

Quality factor, Q = XL/R = 461.63/100 = 4.6163

Band width (BW) of the pass-band filter: This is the range of frequencies for which the current (or output voltage) is equal to or greater than 70.7% of its value at the resonant frequency. The frequency at which the output of a filter is 70.7% of its maximum are called "cutoff frequencies" and are rebelled as f_1 and f_2 alongside (lower and upper) of the resonant frequency f_r. Other names are *-3dB frequencies, critical frequencies and half-power frequencies.*

Band width, BW = f_r/Q

= 1565/4.6163

= 339Hz

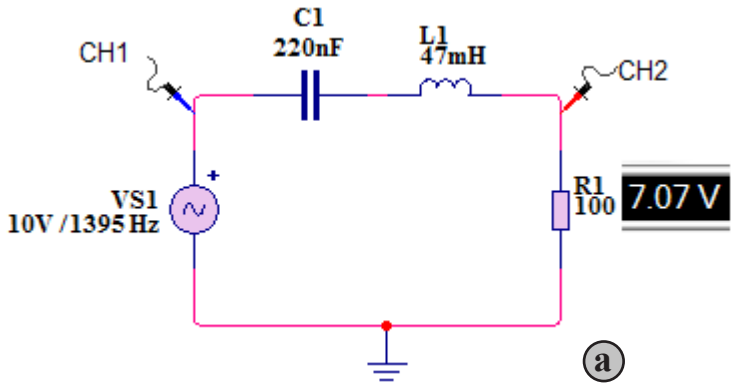
Also BW = f_2-f_1

$f_1 = f_r$ - BW/2

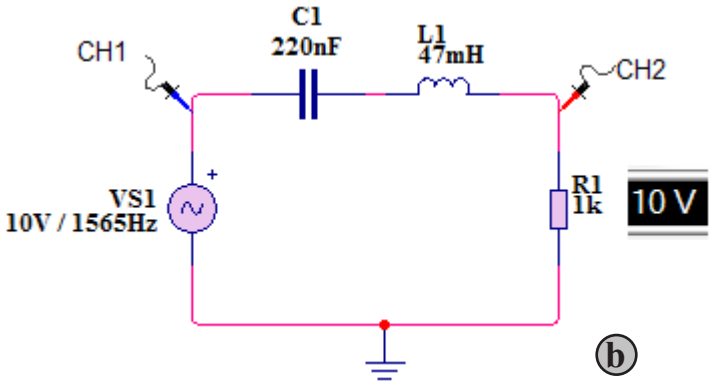
= 1565Hz -169.5Hz = 1395.5Hz

$f_2 = f_r$ + BW/2

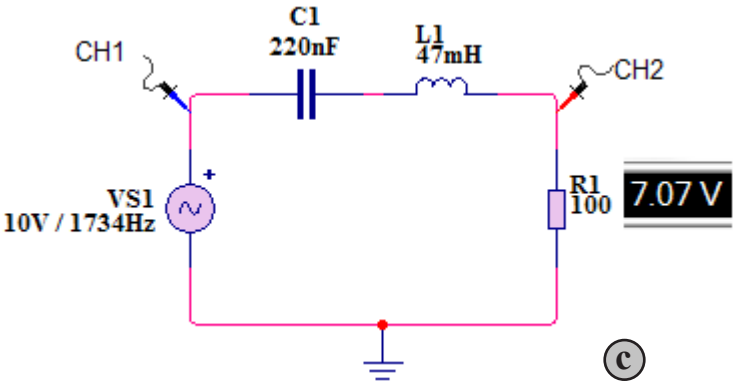
= 1565Hz + 169.4Hz = 1734.5Hz



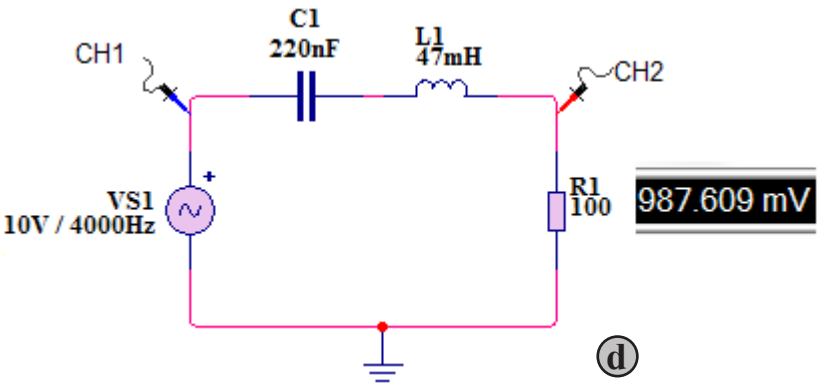
(a) As the frequency increases to f_1, V_{out} increases to 7.07V



(b) As the frequency increases from f_1 to f_r, V_{out} increases from 7.07V to 10V



(c) As the frequency increases from f_r to f_2, V_{out} decreases from 10V to 7.07V

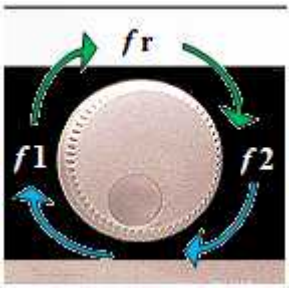


(d) As the frequency increases above f_2, V_{out} decreases below 7.07V

Figure 5-49: (a), (b), (c) and (d) are Series RLC circuits used as band-pass filter

Procedure

1. Connect a 100 Ω resistor, 47 mH inductor and (no polarized) 220 nF capacitor in series with a signal generator as shown in the circuit of figure 5-50.
2. Make sure that the ground of oscilloscope and that of signal generator are connected together.
3. Set the function generator to output a 10V rms sine wave.
4. Set both channel 1 (CH1) and channel 2 (CH2) to 5Volt/Division
5. Connect the channel 1 (CH1) to the input of the circuit and the channel 2 (CH2) at the output (on the terminal of the resistor)
6. Change the frequencies by using the knob shown below and take the resulting data to form a table of V_s (input voltage) and V_{out} (voltage on 100Ω resistor R_1) for a range of frequencies, f, from about $f_r/2$ to $2f_r$ or for more exercise from 100Hz to 6Khz with 100Hz interval



Note that for above circuits, figure 5-49, f_1 and f_2 are the frequencies where V_{out}/V_s falls to $1/\sqrt{2}$ of the peak value of the input.

7. From obtained result, plot a graph of normalized values of Vout/Vs versus frequency. (here normalized means divide all the V_{out}/V_s values by the maximum value which occurs at f_r. This means when the graph is plotted its peak value will appear to be unit).

Frequencies between f_1 and f_2 are passed through the filter with amplitudes no less than 70.7% (≤7.07V≥) of maximum. The frequencies outside pass-band are reduced to less than 70.7% (<7.07V) of the maximum and are considered to be rejected.

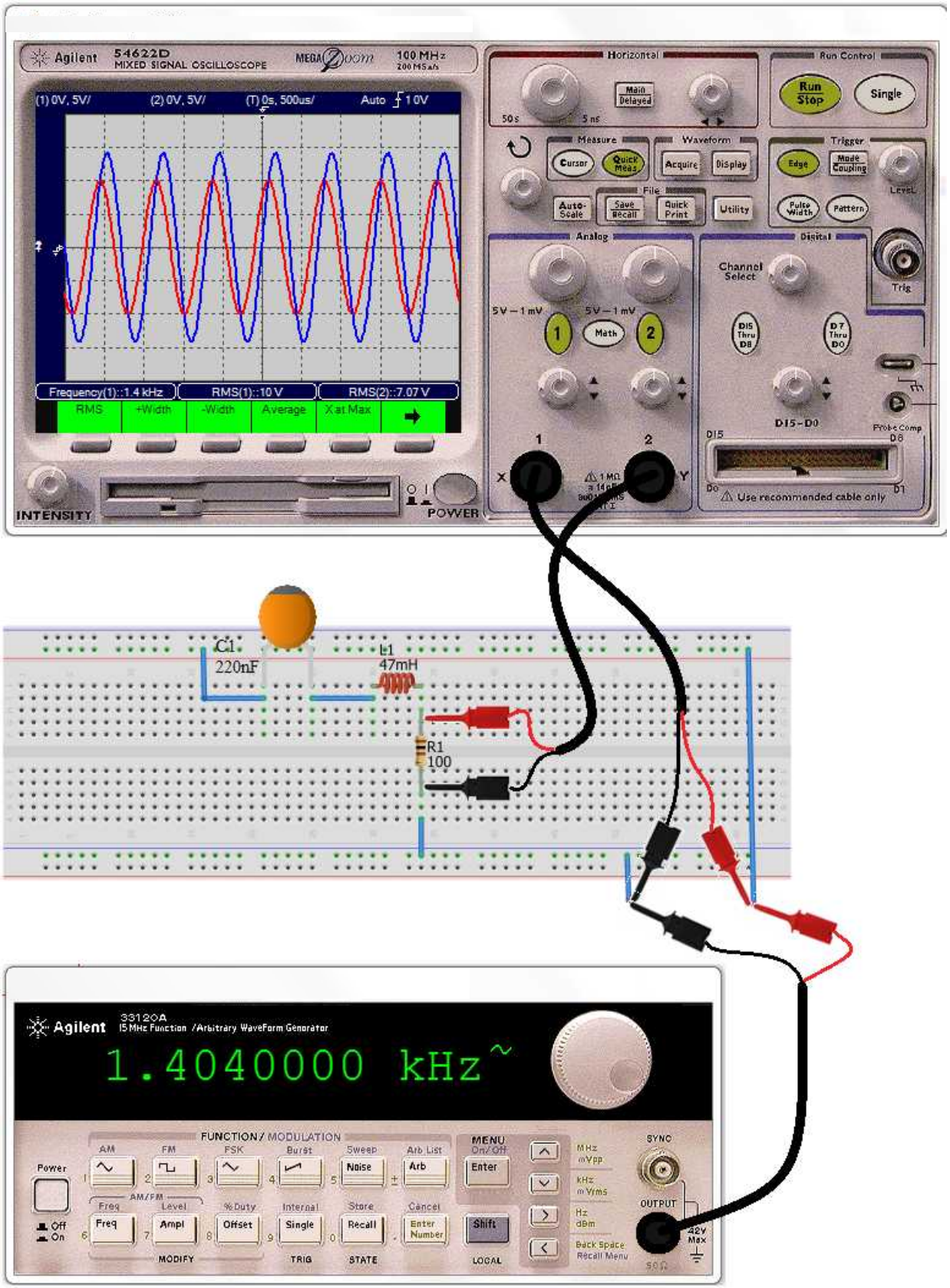


Figure 5-50: Series RLC circuit used as band-pass filter real world circuit connection

We ideally assume that a resonant circuit accepts frequencies within its bandwidth and completely eliminates frequencies outside the bandwidth. Such is not the case, however, because signals with frequencies outside the bandwidth are not completely eliminated. Their magnitude, however, are greatly reduced. The further the frequencies are from the cutoff frequencies, the greater the reduction as illustrated in graph figure 5-51 and figure 5-52.

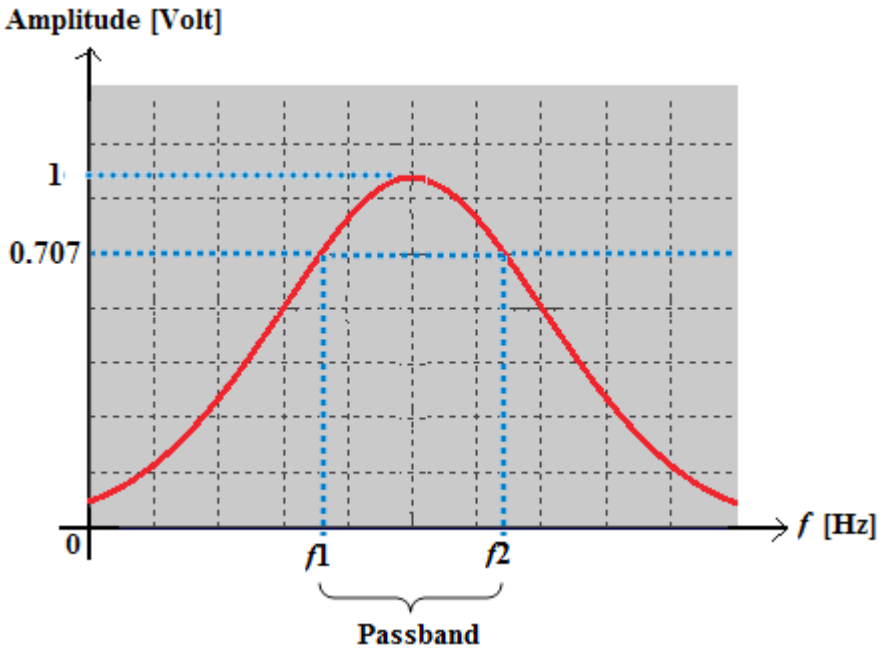


Figure 5-51: Generalized response curve of a series resonant band-pass filter

Frequencies from f_1 and f_2 are assumed to be passed equally. All frequencies outside the passband are eliminated.

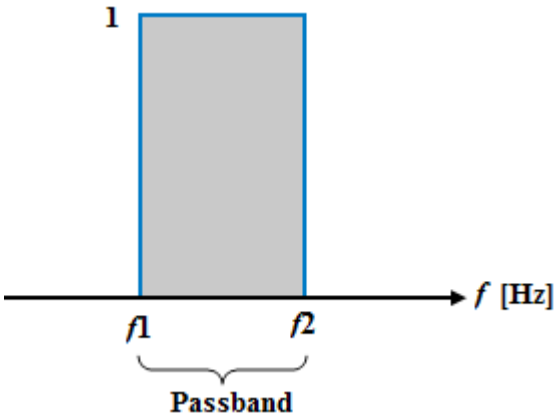


Figure 5-52: Generalized selectivity curve of a band-pass filter

Compare the practical result to the theory you may well find that these values are not the same. Part of the reason for this difference is the fact that inductor also has a resistance, which you have not taken into account. The other thing, the resistor in this circuit is the resistance of the inductor plus any resistance contributed by the function generator. Normally the function generator has an output impedance of 50 Ω.

Verify this by measuring the resistance of the function generator output with the generator turned on but the output voltage set to 0 V.

When a coil is made of a certain material (for example, insulated copper wire), that wire has a certain resistance per unit of length. When many turns of wire are used to construct a coil, the total resistance may be significant. This inherent resistance is called the *dc resistance or winding resistance.* Although, this resistance is distributed along the length of the wire, it is sometimes indicated in a schematic as resistance appearing in a series with the inductance of the coil. In many application, the winding resistance can be ignored and the coil can be considered as an ideal inductor. In other cases, the resistance must be considered.

Safety point

Be careful when working with inductors because high induced voltages can be developed due to a rapidly changing magnetic field. This occurs when the current is interrupted or its value abruptly changed.

5. 3. 4. Transformer

A basic transformer is an electrical device constructed of two coils of wire (windings) electromagnetically coupled to each other so that there is a mutual inductance for the transfer of power from one winding to the other. The schematic of a transformer is shown in figure 5-53 part (a). One coil is called the primary winding and the other coil is called the secondary winding. For standard operation, the source voltage is applied to the primary winding, and a load is connected to the secondary winding, as shown in figure 5-53 part (b). The primary winding is the input of the transformer, and the secondary winding is the output winding. It is common to refer to the side of the transformer that has the source voltage as the *primary*, and the side that has the induced voltage as the *secondary.*

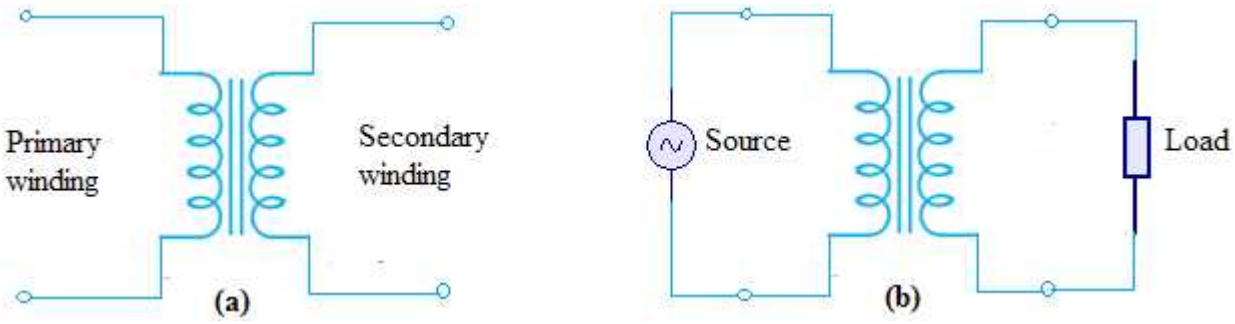


Figure 5-53: Basic transformer, (a) Schematic symbol, (b) source/load connection

The transformer does this by linking together two or more electrical circuits using a common oscillating magnetic circuit which is produced by the transformer itself. A transformer operates on the principals of "electromagnetic induction", in the form of Mutual Induction.

Mutual induction is the process by which a coil of wire magnetically induces a voltage into another coil located in close proximity to it. Then we can say that transformers work in the "magnetic domain", and transformers get their name from the fact that they "transform" one voltage or current level into another.

Transformer Working Principle

A transformer basically consists of two coils wound around a common soft iron core. When an alternating voltage is applied to the primary coil, current flows through the coil which in turn sets up a magnetic field around itself, called *mutual inductance*, by this current flow according to *Faraday's Law* of electromagnetic induction. The strength of the magnetic field builds up as the current flow rises from zero to its maximum value which is given as dΦ/dt. As the magnetic lines of force setup by this electromagnet expand outward from the coil the soft iron core forms a path for and concentrates the magnetic flux. This magnetic flux links the turns of both windings as it increases and decreases in opposite directions under the influence of the AC supply.

However, the strength of the magnetic field induced into the soft iron core depends upon the amount of current and the number of turns in the winding. When current is reduced, the magnetic field strength reduces. When the magnetic lines of flux flow around the core, they pass through the turns of the secondary winding, causing a voltage to be induced into the secondary coil. The amount of voltage induced will be determined by:

$$E = N.d\Phi/dt \text{ (Faraday's Law)},$$

Where

N: Number of coil turns.

E: Induced voltage

Φ: Flux

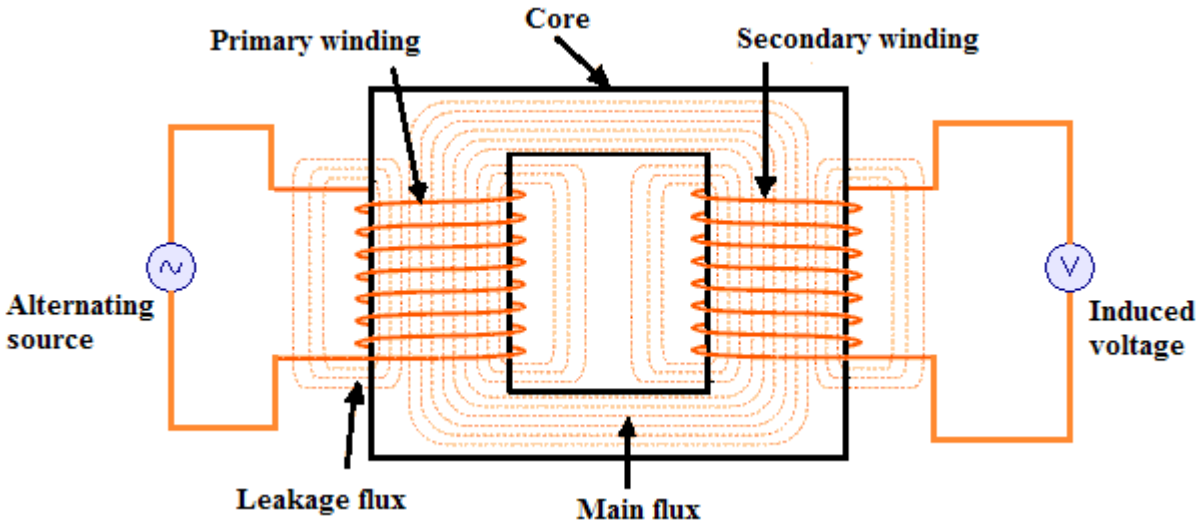


Figure 5-54: Transformer structure

Also this induced voltage has the same frequency as the primary winding voltage. Then the same voltage is induced in each coil turn of both windings because the same magnetic flux links the turns of both the windings together. As a result, the total induced voltage in each winding is directly proportional to the number of turns in that winding. However, the peak amplitude of the output voltage available on the secondary winding will be reduced if the magnetic losses of the core are high.

- **Voltage Transformer**

The transformers are classified based on voltage levels, Core medium used, winding arrangements used and installation place etc. In this tutorial, we are going to describe the most transformers used for home appliances and in electronics circuits as well, that is voltage transformer.

The Voltage Transformer can be thought as an electrical component rather than an electronic component. Transformers are capable of either increasing or decreasing the voltage and current levels of their supply, without modifying its frequency, or the amount of Electrical Power being transferred from one winding to another via the magnetic circuit. I.e. if the voltage is high at secondary side then the current drawn from the secondary will be low so that the power will be the same. Same as in the reverse case when the voltage is low the current drawn will be high. Thus, transformers are classified as step-up and step-down transformers as the voltage ratios from primary to secondary. These are widely used transformer types for all the applications

One of the main reasons that we use alternating AC voltages and currents in our homes and workplace's is that it can be easily generated at a convenient voltage, transformed into a much higher voltage and then distributed around the country using a national grid of pylons and cables over very long distances. The reason for transforming the voltage is that higher distribution voltages imply lower currents and therefore lower losses along the network.

These high AC transmission voltages and currents are then reduced to a much lower, safer and usable voltage level where it can be used to supply electrical equipment in our homes and workplaces, and all this is possible thanks to the basic Voltage Transformer.

- **Step-up Transformer**

As the name specifies the secondary voltage is stepped up with a ratio compared to primary voltage. This is achieved by increasing the number of coil turns in the secondary as shown in figure 5-55.

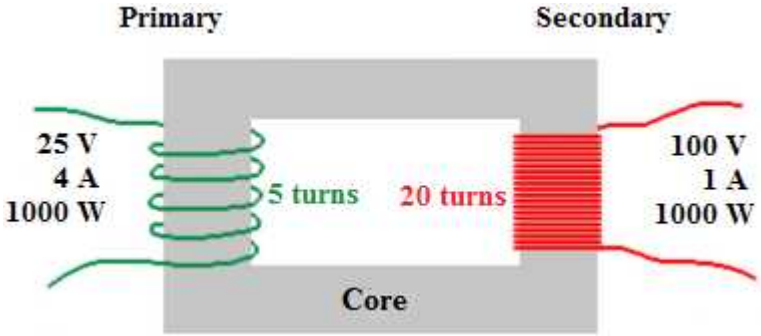


Figure 5-55: Step-up transformer structure example

Generally step-up transformers are used in power plant as connecting transformer of generator to grid. I.e. the Generated low voltage should be suitably stepped up to connect to high voltage grid.

- **Step-down Transformer**

The high voltage applied to the primary winding is stepped down to the secondary winding of the transformer so that the secondary voltage is less than the primary where the name step-down transformer. The winding turns will be high at primary side where as it will be less at secondary side. Example of step-down transformer design is shown in figure 5-56.

The step down transformer is widely used to convert the high grid voltage to the low voltage which can be used at house purposes such as radio receivers, television, etc.

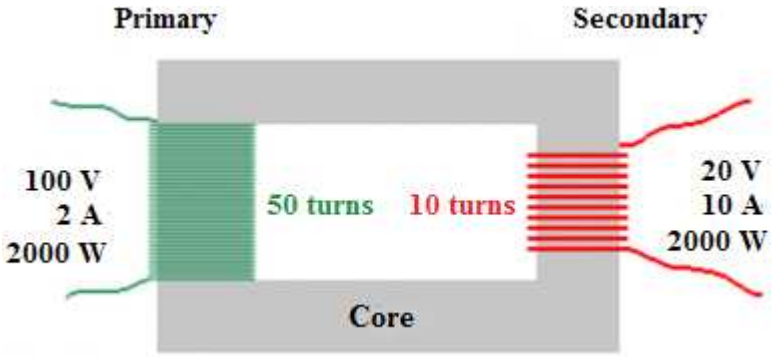
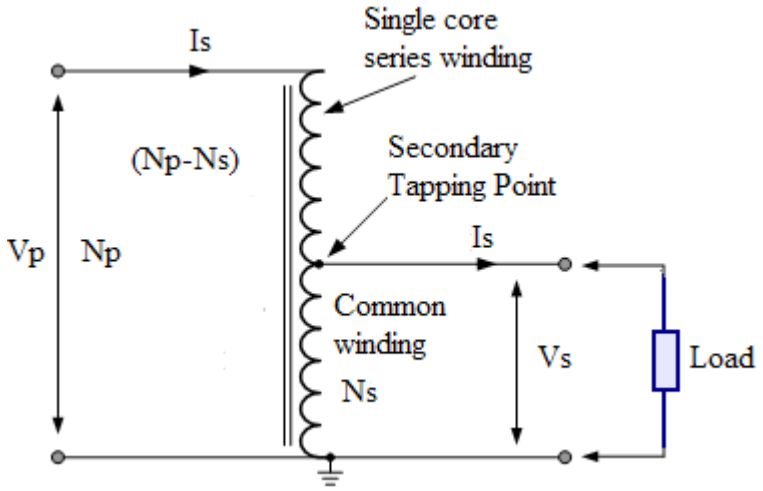


Figure 5-56: Step-down transformer structure example

In power plant the use of this transformer are very high where the grid power supply stepped down and given to corresponding plant auxiliaries during starting of the power plant. Once the plant has started then the voltage stepping down is necessary where the plant auxiliaries will operate at low voltage compared to its generated voltage.

- **Auto Transformer**

Unlike the previous voltage transformer which has two electrically isolated windings called, i.e. primary and secondary, but in auto transformer, both the windings that is primary and secondary windings are connected to each other both physically and magnetically to form only one single voltage winding which is common to both sides. This single winding is "tapped" at various points along its length to provide a percentage of the primary voltage supply across its secondary load. Then the autotransformer has the usual magnetic core but only has one winding, which is common to both the primary and secondary circuits.



Where

V_p: is the Primary Voltage

V_S: is the Secondary Voltage

N_p: is the Number of Primary Windings

N_S: is the Number of Secondary Windings

Figure 5-57: Autotransformer basic schematic

The Autotransformer can also be constructed with more than one single tapping point. Autotransformers can be used to provide different voltage points along its winding or increase its supply voltage with respect to its supply voltage.

Therefore in an autotransformer the primary and secondary windings are linked together both electrically and magnetically. The main advantage of this type of transformer design is that it can be made a lot cheaper for the same VA rating, but the biggest disadvantage of an autotransformer is that it does not have the primary/secondary winding isolation of a conventional double wound transformer.

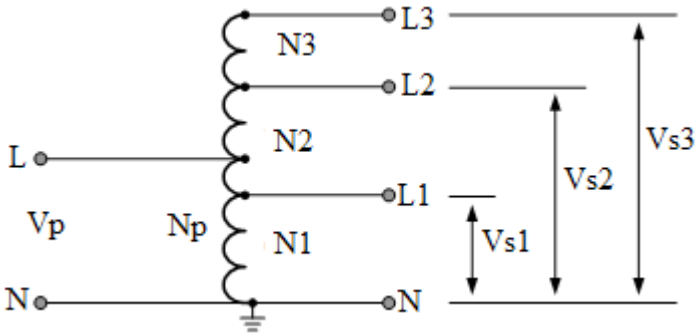


Figure 5-58: Autotransformer with Multiple Tapping Points

The section of winding designated as the primary part of the winding is connected to the AC power source with the secondary being part of this primary winding. An autotransformer can also be used to step the supply voltage up or down by reversing the connections. If the primary is the total winding and is connected to a supply, and the secondary circuit is connected across only a portion of the winding, then the secondary voltage is "stepped-down".

- **Transformer Dot Orientation**

The two coil windings can have a distinct orientation of one with respect to the other. Either coil could be wound around the core clockwise or anticlockwise so to keep track of their relative orientations "dots" are used to identify a given end of each winding.

This method of identifying the orientation or direction of a transformer's windings is called the "dot convention". Then a transformer's windings are wound so that the correct phase relations exist between the winding voltages with the transformers polarity being defined as the relative polarity of the secondary voltage with respect to the primary voltage.

The first transformer, figure 5-59 (1), shows its two "dots" side by side on the two windings. The current leaving the secondary dot is "in-phase" with the current entering the primary side dot. Thus the polarities of the voltages at the dotted ends are also in-phase so when the voltage is positive at the dotted end of the primary coil, the voltage across the secondary coil is also positive at the dotted end. The second transformer figure 5-59 (2) shows the two dots at opposite ends of the windings which means that the transformers primary and secondary coil windings are wound in opposite directions. The result of this is that the current leaving the secondary dot is 180° "out-of-phase" with the current entering the primary dot. So the polarities of the voltages at the dotted ends are also out-of-phase so when the voltage is positive at the dotted end of the primary coil, the voltage across the corresponding secondary coil will be negative.

Then the construction of a transformer can be such that the secondary voltage may be either "in-phase" or "out-of-phase" with respect to the primary voltage.

In transformers which have a number of different secondary windings, each of which is electrically isolated from each other it is important to know the dot polarity of the secondary windings so that they can be connected together in series-aiding (secondary voltage is summed) or series-opposing (the secondary voltage is the difference) configurations.

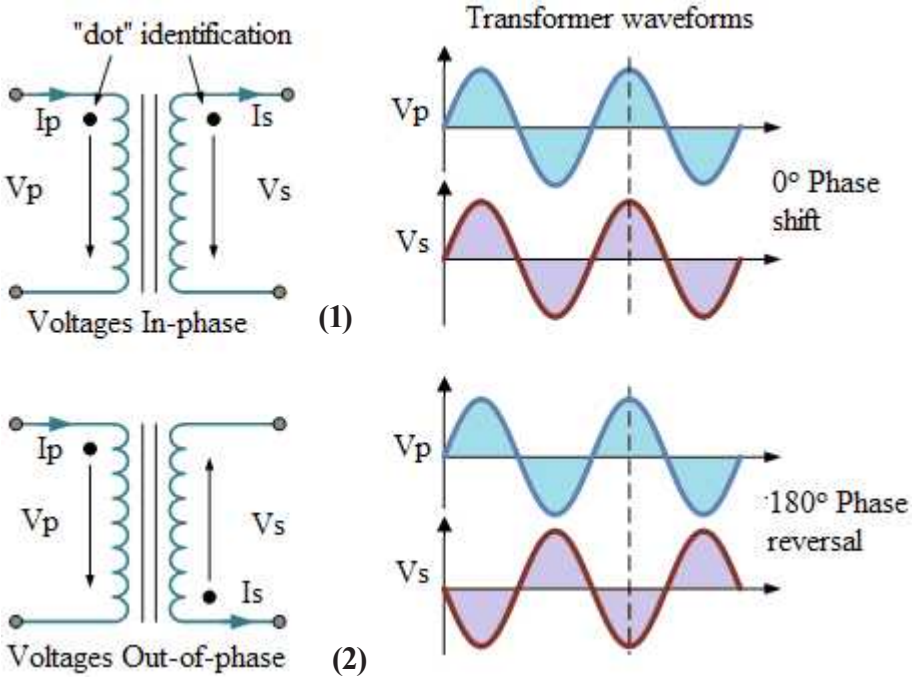


Figure 5-59: Transformer dot orientation; (1) voltages in-phase, (2) voltages out of phase

- **Transformer ratio**

The turns ratio of a transformer states that the total induced voltage in each winding is proportional to the number of turns in that winding and also that the power output and power input of a transformer is equal to the volts times amperes, (V x *I*). Therefore

$$\text{Power}_{(\text{Primary})} = \text{Power}_{(\text{secondary})}$$
$$Vp * Ip = Vs * Is$$
$$\text{Then } Vp * Ip/Vs = Is$$
$$Vp/Vs = Is/Ip$$

But the voltage ratio of a transformer is equal to the turns ratio of a transformer.
"voltage ratio = turns ratio" Then the relationship between the voltage, current and number of turns in a transformer can be linked together and is therefore given as:

$$n = Np/Ns = Vp/Vs = Is/Ip$$

Where:

$N_P/N_S = V_P/V_S$ - represents the voltage ratio
$N_P/N_S = I_S/I_P$ - represents the current ratio

Note that the current is inversely proportional to both the voltage and the number of turns. This means that with a transformer loading on the secondary winding, in order to maintain a balanced power level across the transformers windings, if the voltage is stepped up, the current must be stepped down and vice versa. In other words, "higher voltage — lower current" or "lower voltage — higher current".

- **Series and Parallel Connected Secondary Transformer**

Voltage transformers can be connected to operate from power supplies of different voltage levels. For example, let's say that the primary winding could have a voltage rating of 220/110V on the primary and 12/24V on the secondary. To achieve this, each of the two primary windings is, therefore, rated at 110V, and each secondary winding is rated at 12V. The transformer must be connected so that each primary winding receives the proper voltage. Consider the circuit figure 5-60.

Series Connected Secondary Transformer

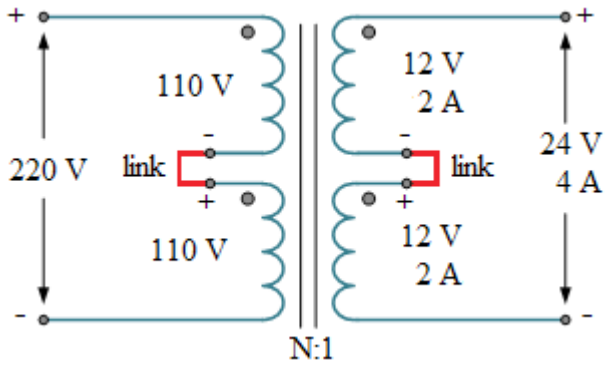


Figure 5-60: Series connected secondary transformer

In this example, the two 110V rated primary windings are connected together in series across a 220V supply as the two windings are identical, half the supply voltage, namely 110V, is dropped across each winding and the same primary current flows through both. The two secondary windings rated at 12V, 2A each are connected in series with the secondary terminal voltage being the sum of the two individual winding voltages giving 24 Volts. As the two windings are connected in series, the same amount of current flows through each winding, then the secondary current is the same at 2 Amps. So for a series connected secondary, the output in our example above is rated at 24 Volts, 2 Amps. Consider the parallel connected transformer of figure 5-61.

Parallel Connected Secondary Transformer

Here we have kept the two primary windings the same but the two secondary windings are now connected in a parallel combination.

As before, the two secondary windings are rated at 12V, 2A each, therefore the secondary terminal voltage will be the same at 12 Volts but the current adds. Then for a parallel connected secondary, the output in our example above is rated at 12 Volts, 4 Amps.

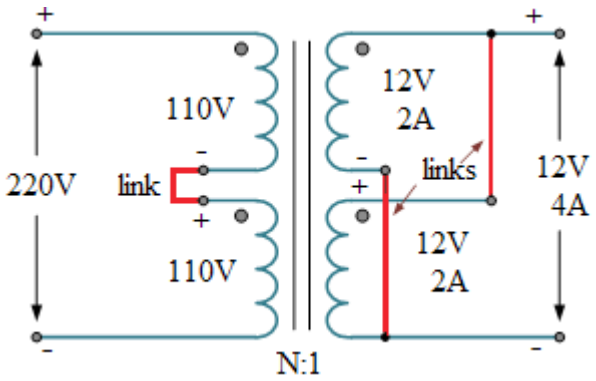


Figure 5-61: Parallel connected secondary transformer

- **Transformer testing**

Transformers are key electrical components in power supplies and electronic circuits. Though, they are reliable and have no moving parts, sometimes transformers fail, rendering the equipment it powers inoperable where they need to be tested. Different methods can be used to test home appliances' transformer functionality. Some simple and reliable methods are described below.

Experiment 5-15: Test a transformer by using a function generator (ac source)

If you suspect a miss function of a transformer in a part of equipment, you can carry out a simple test with a function generator that checks the transformer's basic functions. The function generator's ac signal tests the integrity of the primary and secondary windings; broken wires or shorts inside the transformer will produce no output. The method is safe as it avoids the high voltages usually present inside electronic equipment.

Part list

No	Item	Specification
1	5V/50Hz ac supply	Function generator
2	Voltmeter	Digital multimeter

Procedure

1. Disconnect the equipment containing the transformer from the wall outlet, if the transformer is in a circuit.Turn the function generator on and set its frequency to 50 Hz.
2. Touch the digital multimeter's probe tips to the function generator's output. Set the multimeter to read AC volts.
3. Set the function generator's signal amplitude to 5 volts by monitoring the multimeter's display as you adjust the function generator's amplitude control. Disconnect the multimeter from the function generator.
4. Connect the function generator's output to the transformer's two primary wires.
5. Touch the multimeter's probe tips to the transformer's two secondary wires. A good isolation transformer reads about 5 volts AC on the meter. A good step-down transformer produces from 100 millivolts to 1 volt AC, depending on its rated output voltage.

If the output reads only a few millivolts or less on the multimeter, the transformer is faulty.

Figure 5-62: Testing transformer form a function generator

Experiment 5-16: Test transformer from wall outlet socket

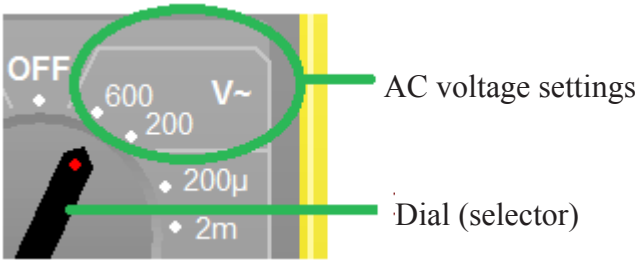
Checking a transformer for its proper operation can be conducted by using voltmeter to test the voltage presence. The transformer can be divided into two parts. The supply voltage or primary which is usually high voltage for step-down transformer, and the secondary or low voltage. What we need to determine is that we are getting correct supply voltage according to the transformer specifications and the supply voltage from network.

Part list

No	Item	Specification
1	Voltmeter	Digital multimeter
2	Transformer	220V/12V, 50Hz, 1A Transformer

Procedure

1. Set the multimeter to read AC volts at a scale equivalent to the highest voltage you are expecting to measure. The next scale higher than 220 volts AC on a lot of meters is 600. Most digital multimeters have a dial to turn for the different settings and scales them, use this dial to set to the desired range except if you are using auto range multimeter. Make sure that the read lead of multimeter is connected on VΩ jack and black lead to the COM jack of multimeter.



2. Test incoming voltage from wall outlet socket. If no voltage is present in either case you have a bad breaker or voltage has became interrupted somewhere along the way and needs to be repaired. If voltage is present you should read about 220 volts ac on your meter. Then you have proper supply voltage and now you can test your transformer.
3. Locate the transformer wires. You should be able to read transformer's main plate information in order to know which wires are for primary and that of the secondary windings otherwise you can damage your transformer. Some transformer have color-code on their lead which can help to indentify the wires but let us refer on a transformer where the color code has faded to the point as to be unreadable. The supply voltage wires coming from the transformer can be of many colors; the most common for a 220 volt ac transformer supply voltage is black and white, the black being the hot wire and the white being the neutral common wire or, black and red with red as live wire. If the indication on main plate is +, 0, -, (220V/6-0-6 for example) this is a centre tapped transformer where the 3 wires which have continuity are for secondary windings and the remaining two wires having the continuity are for primary winding. If the indication on the main plate of a transformer is not readable refer to the winding section. The winding with thin (small) section is for primary supplying voltage 220V while the winding with big section is for secondary, 12VAC for this experiment. Transformer windings have a phase relationship, but it is typically not important for power supplies. Unless one of the wires has continuity to the transformer core, the polarity doesn't matter.
4. Connect the primary of a transformer on the wall outlet socket.

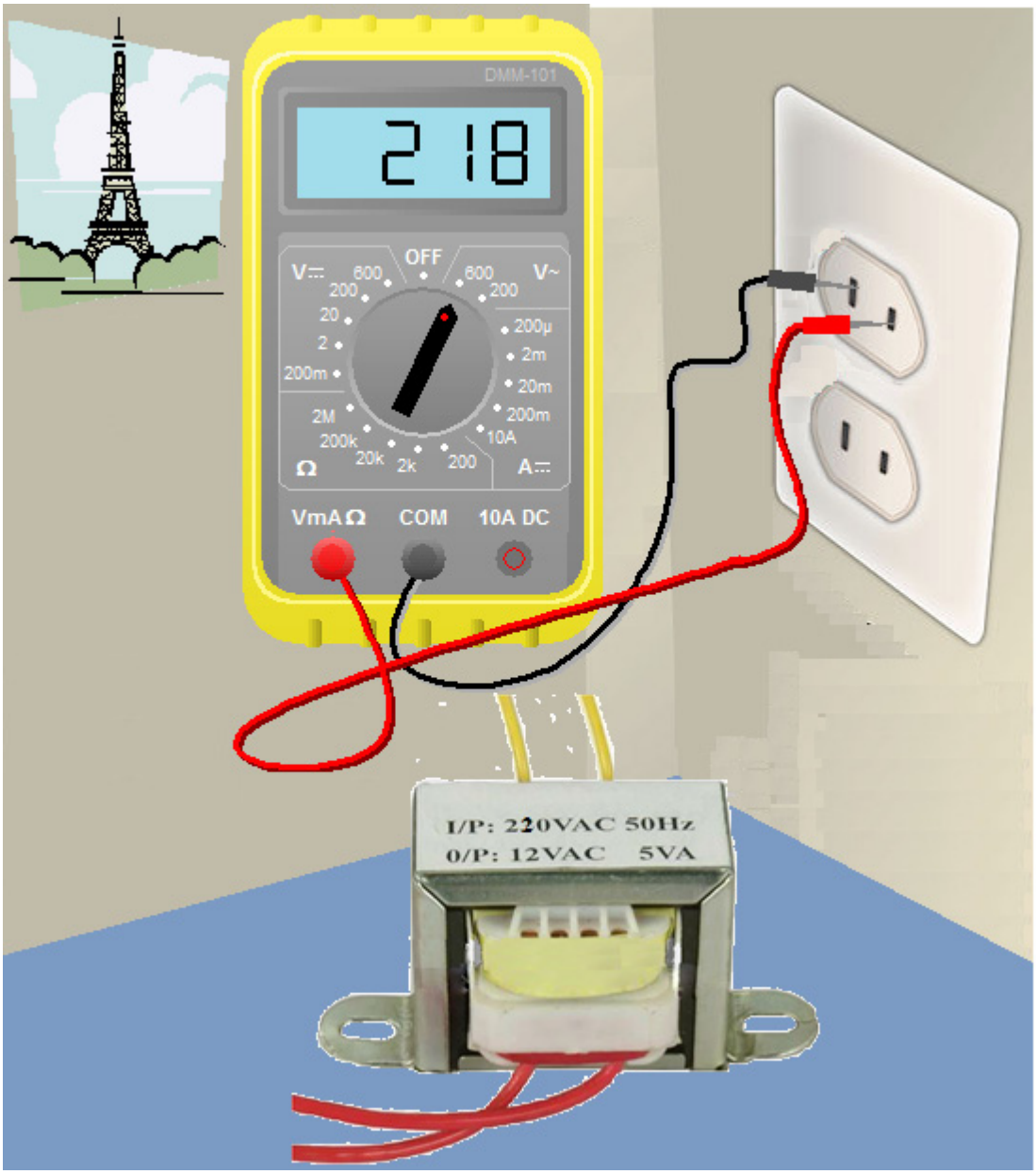


Figure 5-63: Testing transformer from wall outlet socket real

5. Set the multimeter to read 12 volts AC and connect the leads of multimeter to the secondary winding of a transformer and observe the reading on multimeter. The reading should be at about 12V. If the reading is 11V or 13V there everything is good up to the transformer. If there is no power go further back on the line and measure the voltage. Keep going until you find voltage. Look for the problem between the point with the voltage and the last point checked that had no voltage. If there is no voltage there then the transformer itself is faulty and you need to replace the transformer.

Safety point

This test should only be done by an experienced person familiar with electricity.

Inspect Transformer Visually

Overheating, which causes the internal wiring of the transformer to run at elevated temperatures, is a common cause of transformer failure. Whenever a winding has shorted turns, applying full input voltage may spell disaster in the form of a smoking transformer. If the transformer exterior is swelling or shows what appear to be burn marks, don't waste your time by testing the transformer. This is the sign that shows you that the transformer is burnt and can not work.

Experiment 5-17: Test transformer from a circuit

Transformers are key electrical components in power supplies. Transformers change the voltage of the system to suit the electronics equipments. Step-down transformers are found in electric power company systems and in a multitude of appliances for household and industrial uses. Size ranges are found from a cell phone charger up to one the size of power house equipment to the end of a high voltage transmission line. For standard household transformer testing a digital multimeter (DMM) makes a good test.

Part list

No	Item	Specification
1	Voltmeter	Digital multimeter
2	DC power supply motherboard	220V/12V, 50Hz, 1A Transformer

Procedure

1. Determine the wiring of the transformer. The transformer should be clearly labeled. However, it is always best to obtain a schematic of the circuit containing the transformer to determine how the transformer is connected. The schematic for the circuit will be available in the product documentation or on the website of the circuit manufacturer.
2. Identify the transformer inputs and outputs. The first electrical circuit, which is generating the magnetic field, will be connected to the primary of the transformer. The voltage being supplied to the primary should be on both the transformer label and the schematic. The second circuit that is receiving power from the magnetic field will be connected to the secondary of the transformer.

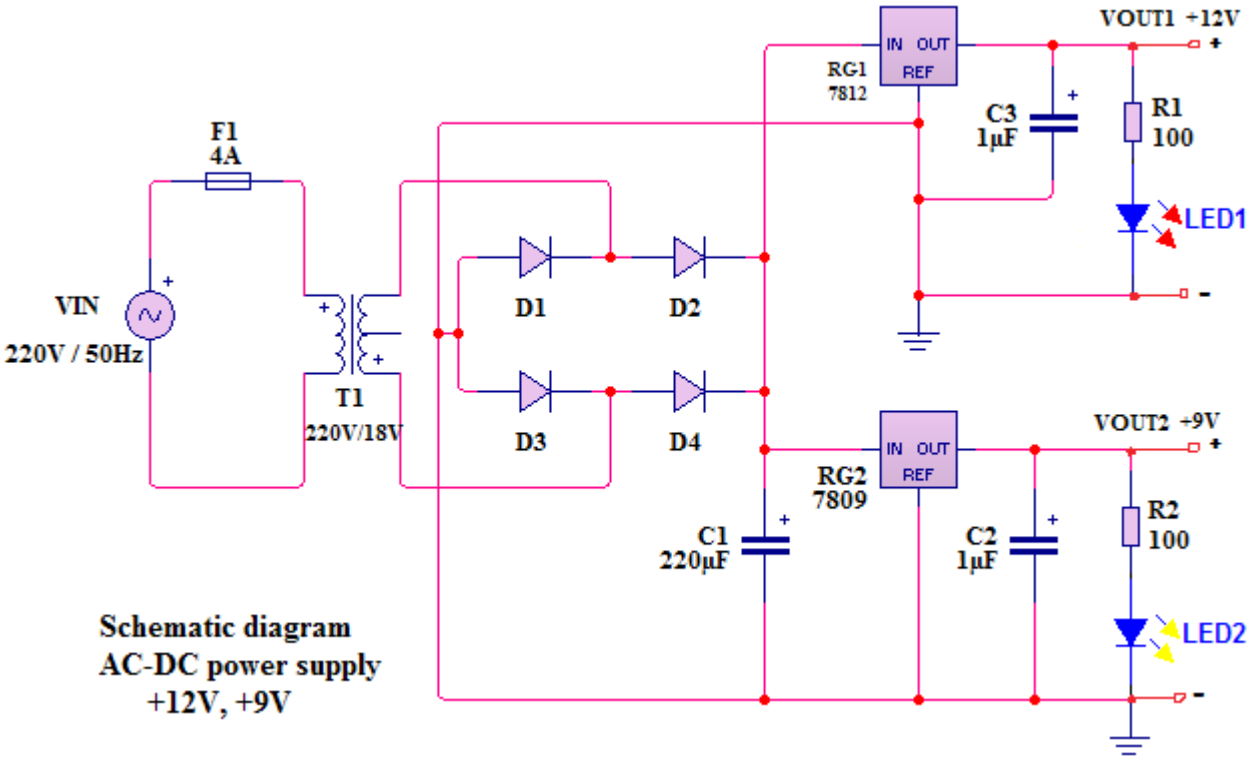


Figure 5-64: Schematic circuit diagram of an AC-DC power supply +12VDV and +9VDC

The voltage being generated by the secondary winding should be on both the transformer label and the schematic.

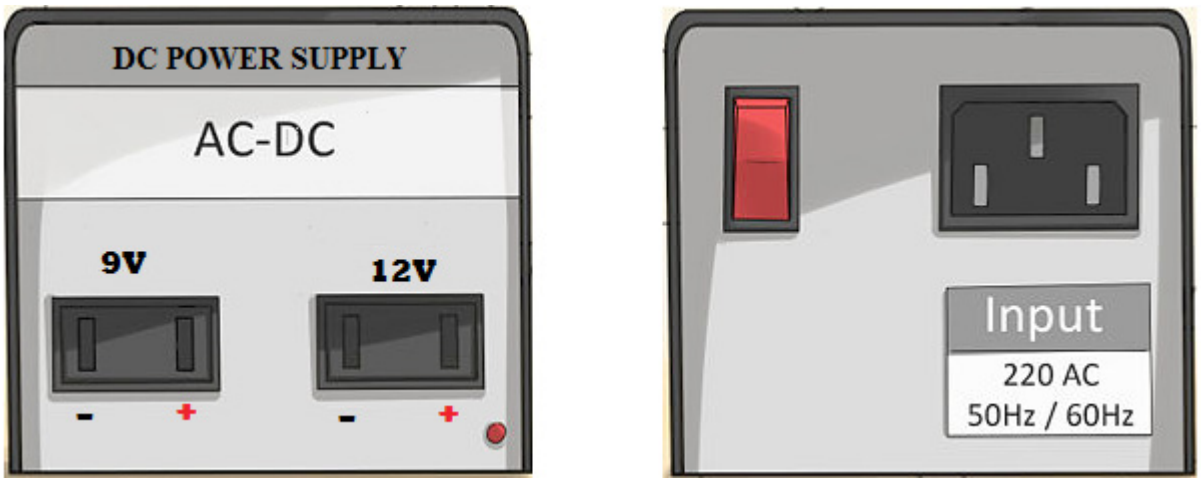


Figure 5-65: Input and output of an AC-DC +12VDC, +9VDC supply

3. Determine the output filtering. It is common to attach capacitors and diodes to the transformer secondary to shape the AC power from the output into DC power. This filtering and shaping will not be available from the transformer label. The filtering and shaping will be shown on the schematic.

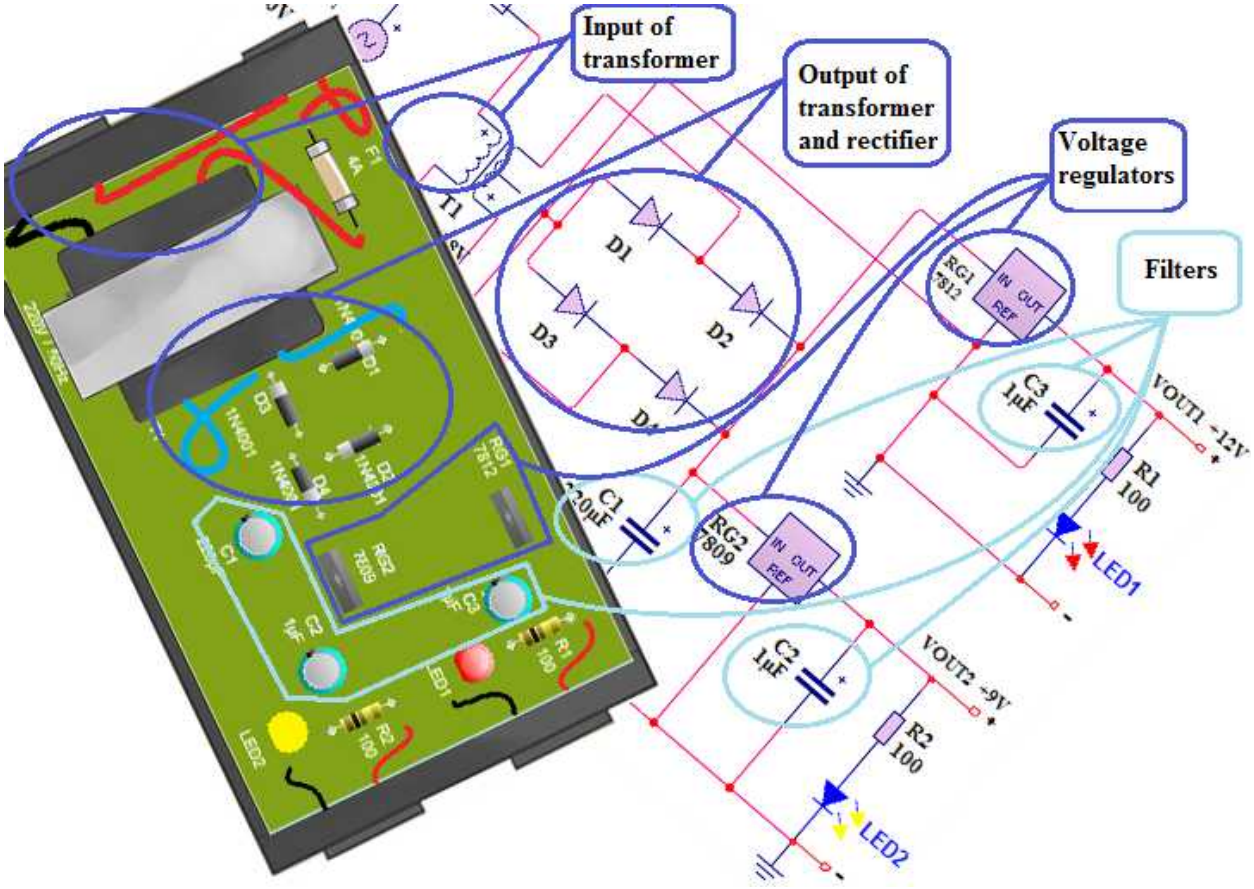


Figure 5-66: Locating different parts of an AC-DC power supply's motherboard

4. Prepare to measure circuit voltages. Remove covers and panels as necessary to gain access to the circuits that contain the transformer. Acquire a digital multimeter (DMM) to take the voltage readings. Arrange the multimeter's lead with red lead connected to VΩ jack and black lead connected to COM jack of multimeter.
5. onfirm proper input to the transformer. Apply power to the circuit. Use the DMM in AC mode to measure the transformer primary voltage. Set multimeter to read AC voltage at 600V scale. If the measurement is less than 80 percent of the expected voltage, the fault could lie in either the transformer or the circuitry providing the primary with power. In this case, the primary must be separated from the input circuit. If the input power (not the disconnected transformer primary) climbs to the expected value, then the primary of the transformer is faulty. If the input power does not go up to the expected value, then the problem lies not with the transformer, but with the input circuitry.

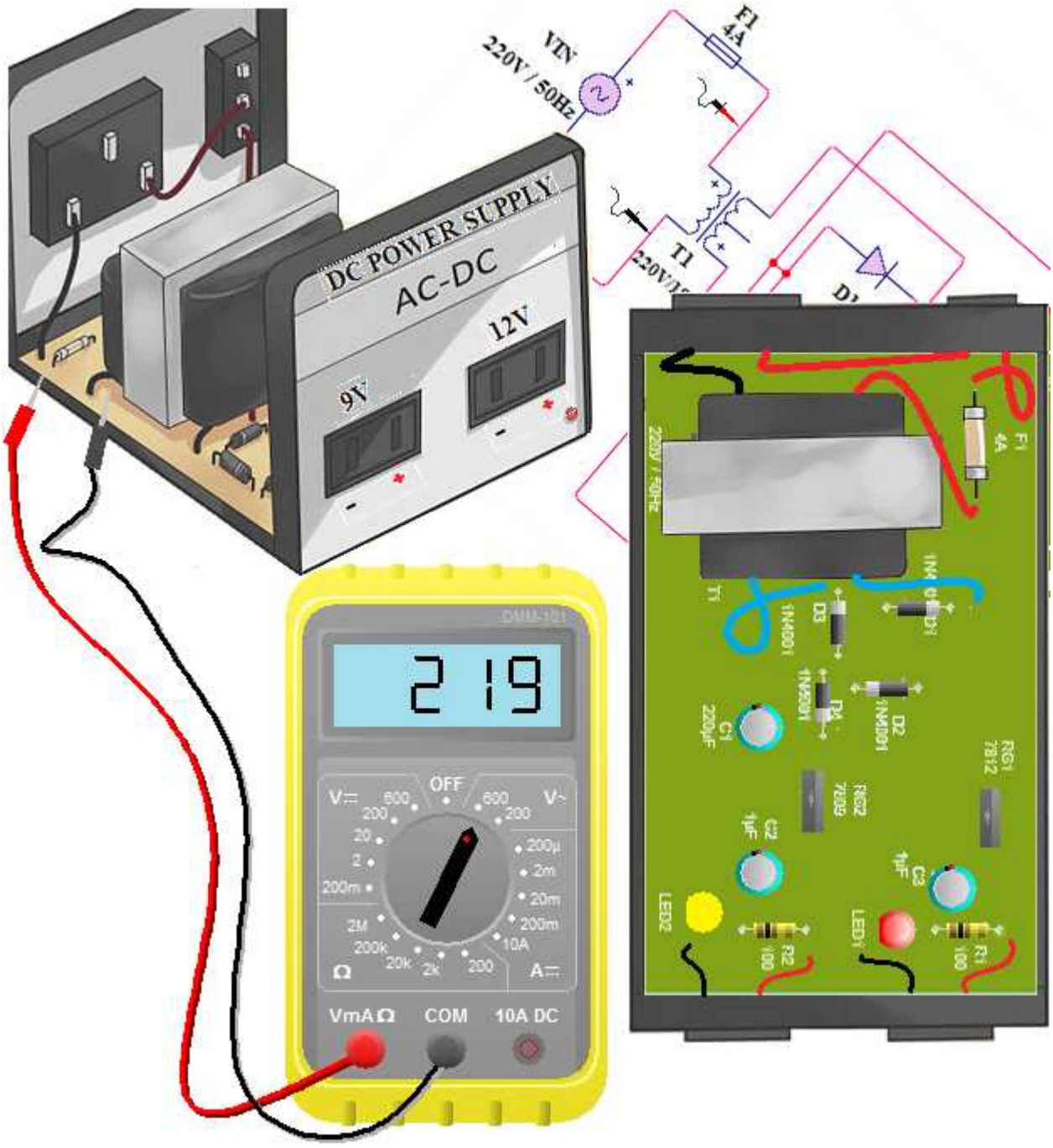


Figure 5-67: Measuring the input AC supply from motherboard of an AC-DC supply connection circuit

6. Measure the secondary output of the transformer and regulators. If you have determined that there is no filtering or shaping being performed by the secondary circuitry, use the AC mode of the DMM. If there is filtering and shaping in the secondary circuitry, use the DC scale of the DMM. Set the multimeter in 20VDC scale. If the expected voltage is not present on the secondary, either the transformer or a filtering or shaping component is faulty. Filtering (smoothing) capacitor is located directly at the output of diode rectifier and the shaping capacitor at the output of regulators. Test the filtering and shaping components

separately. If the testing of the filtering and shaping components shows no problems, then the transformer is faulty and needs to be replaced.

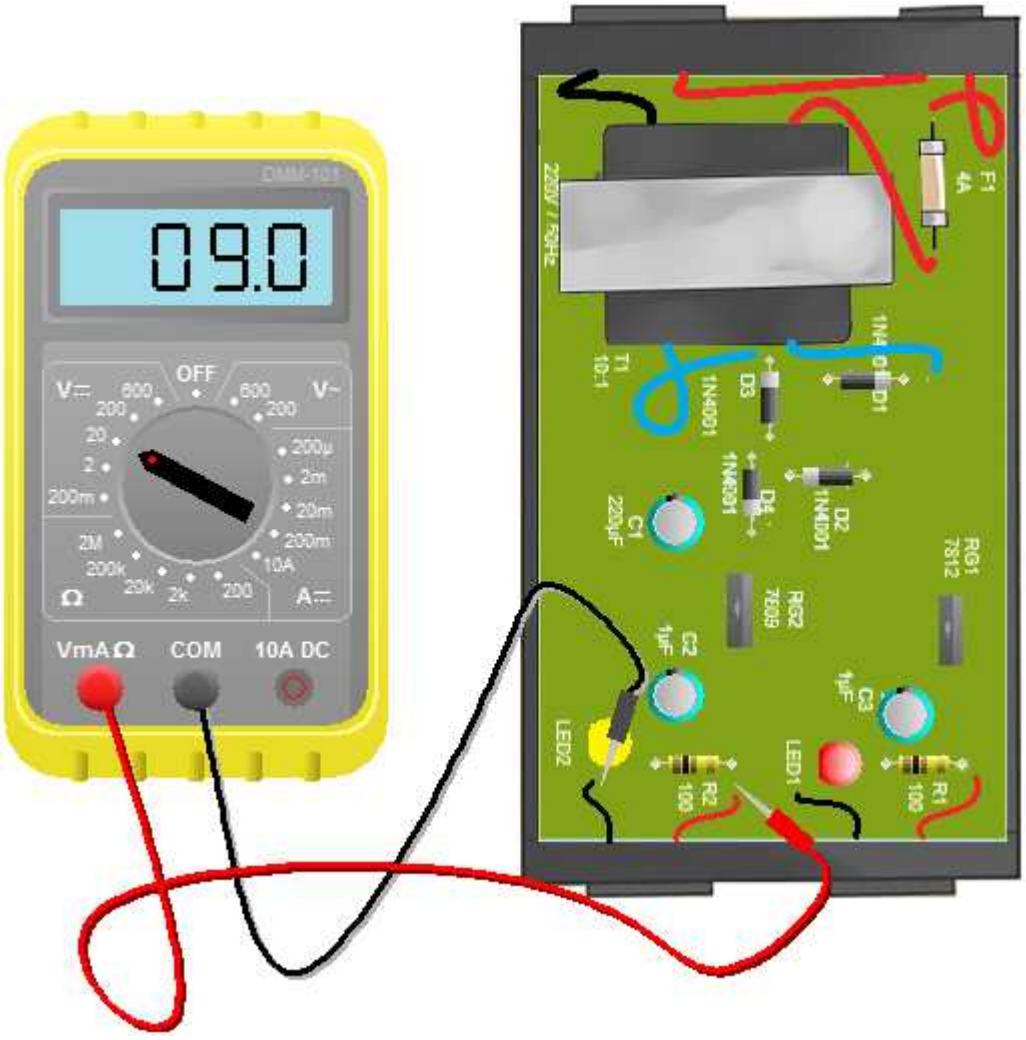


Figure 5-68: Measuring the output from motherboard of an AC-DC supply, real world circuit connection

- **Identifying Transformer Windings**

Most of technician who repair vintage electronic equipments, it is not unusual to have several power transformers that have either been removed from some old radio or other piece of equipment lying around. Due to the expense and availability of new power transformers, it would be nice to identify the windings and voltages of these spare units so that they could be re-used.

Most of power transformers come with color-coding on their leads. If the color-coding on the leads is still readable then you only have to refer to the chart to determine the windings. But often the color coding on the leads of these transformers has faded to the point it is difficult or impossible to read the color code and know which winding. By using the procedures outlined here, you should be able to identify the windings so the next time you discover the transformer in the set you are about to restore is defective, perhaps one of those spare transformers will qualify as a replacement unit. On a transformer where the color code has faded to the point as to be unreadable, there

is a technique to identify the various windings. The ohm-meter is the test instrument we use to accomplish this task.

Below is a diagram of a typical power transformer. This one has a primary winding with a center tapped and a secondary winding also with a center tapped. The diagram gives the color code of the leads for each winding.

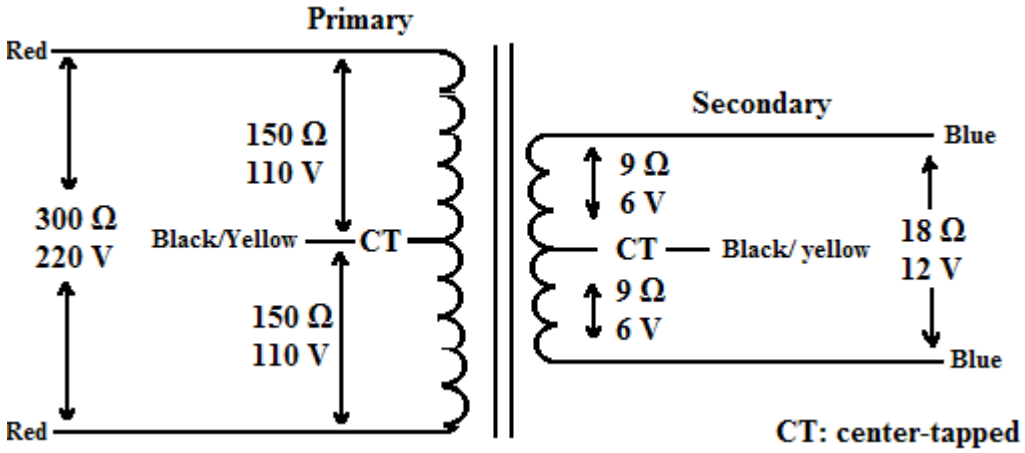


Figure 5-69: Identifying transformer windings

As can be seen from the diagram, each winding will have continuity from one lead of the winding to the other, but there should be no continuity between different windings, i.e. primary and secondary winding. It is possible to have a secondary with multiple windings which provide different voltages. Also, each set of windings will have a resistance value determined by the number of turns and size of the wire. So we can use the ohm-meter to determine which leads have continuity and use the resistance reading to determine which winding is primary and that of secondary (low and high voltage windings), broken, etc.

Part list

No	Item	Specification
1	Ohmmeter	Digital multimeter
2	Transformer	220-110V/6-0-6V, 50Hz, 2A Transformer

Procedure

1. Set the ohmmeter to 200 Ω scale that gives the lowest ohms reading, and calibrate the meter so when the test leads are shorted the meter reads zero ohms. The lowest reading scale is use as the windings will have very low resistance with exception of the high voltage winding. Now pick one of the transformer leads and clip one test lead of the meter to that lead. With the other meter lead, begin checking the other transformer winding leads. Make sure that the transformer is not connected to the supply system. When you find the other lead of the winding under test, the ohm-meter will show continuity.
2. Make a note of the resistance reading. With the first lead still attached, check all other leads to see if any others also have continuity with the first lead. If so, make a note of that reading also. If three leads have continuity, then this winding has a center-tap. Tag these

leads as being checked, and proceed to check the other leads in the same manner, noting the resistance readings.

3. After all leads have been checked and tagged, it can be determined which windings are from these readings. Since the high voltage winding has the most turns of wire, it will have the highest reading; secondary winding have only a few turns of larger wire and will have very low readings, with the primary winding having a resistance somewhere in between. A lead that has no continuity with any other lead indicates an open winding.

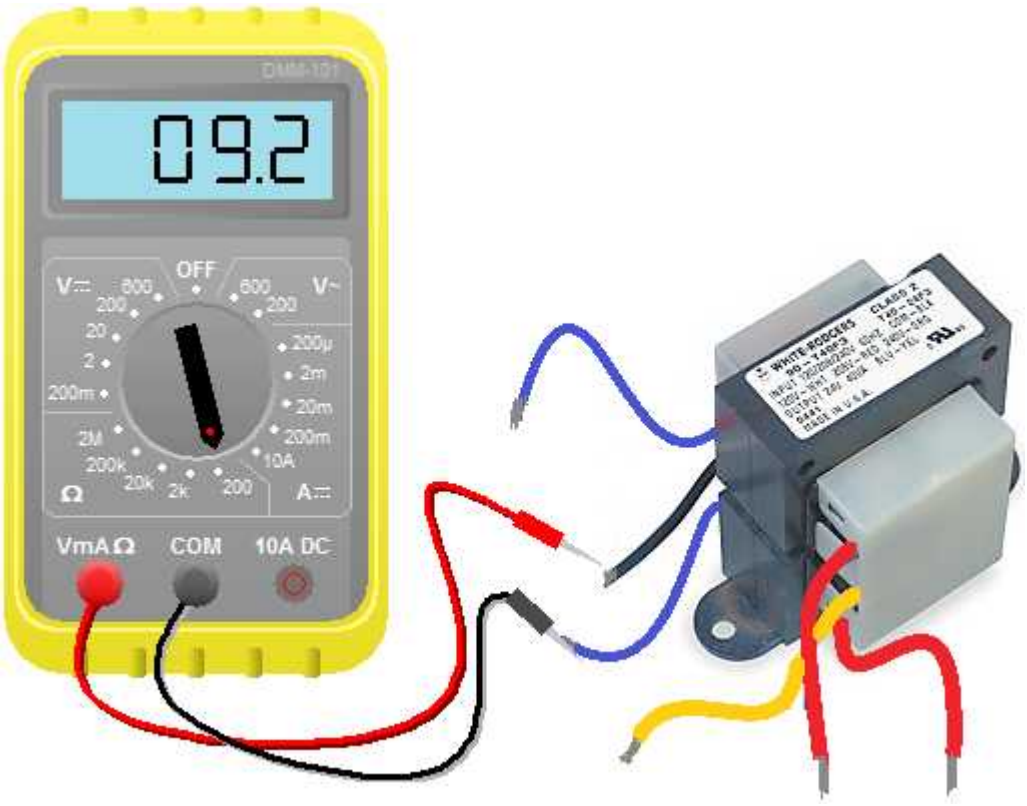


Figure 5-70: Identifying transformer windings using Ohmmeter

4. A center-tapped winding will give a resistance reading between the center-tap and the outer windings equal to approximately one-half of the resistance of the two outer windings; however, on secondary windings the resistance may be low so that it may be hard to tell the center-tap from the outer leads. We will be able to determine the center-tap when we take voltage readings as outlined later. The table 5-17 shows typical readings for a transformer shown in the above schematic diagram.

Winding		Resistance	Corresponding Voltage
Primary	1st Ending terminal - center tapped	150 Ω	110 V
	Center-tapped – 2nd ending terminal	150 Ω	110 V
	1st Ending terminal - 2nd ending terminal	300 Ω	220 V
Secondary	1st Ending terminal - center tapped	9 Ω	6 V
	Center-tapped – 2nd ending terminal	9 Ω	6 V
	1st Ending terminal - 2nd ending terminal	18 Ω	12 V

Table 5-17: Examples of identifying the various windings by the difference in the resistance of the windings

Note: These resistances are approximate. Readings may vary by several ohms from one transformer to the next. The idea is not to be concerned with the exact resistance of the windings, but to identify the various windings by the difference in the resistance of the windings

Transformer Replacement

When replacing a transformer in household electronic equipments, consideration must be given to the power handling capabilities of the replacement unit. One rule of thumb is, if the replacement unit's physical core size is as large or larger than the original, it will probably work. The true test however will be if the secondary voltages are up to specifications and the unit does not run to warm when under operating conditions. A transformer should not be so warm that you cannot hold your hand on it after it has been operating for 20 to 30 minutes.

RMA (Radio Manufacturers Association) Standard Power Transformer Lead Color Code	
Winding	**Color code**
Primary	Both black if not taped, if tapped other winding may be red
Primary tap (optional)	Black/Yellow
High-voltage secondary	Red
High-voltage Center-tap	Red/Yellow
No. 1 Secondary	Yellow
No. 1 Center-tap	Yellow/Black
No. 2 Secondary	Green
No. 2 Secondary Center-tap	Green/Yellow
No. 3 Secondary	Brown
No. 3 Secondary Center-tap	Brown/Yellow
No. 4 Secondary	Slate
No. 4 Secondary Center-tap	Slate/Yellow

Table 5-18: Standard Power Transformer Lead Color Code based on Radio Manufacturers Association.

Note: The number of secondary windings can vary, and may or not be center-tapped. Windings that are center-tapped, the center-tap will carry the same color as the winding plus a yellow tracer. The exception is the five-volt rectifier winding where the center-tap will carry some other color tracer such as black or blue.

Power Transformer Lead Color Codes Old and New		
Winding	**Old RCA Color Code**	**New Color Code**
Primary	Red	Black
Tapped primary	Start: Red	Black
	Tap: Red and Black	Black and Yellow
	Finish: Black and Red tracer	Black and Red
Rectifier filament	Green and Red tracer	Yellow
Filament (secondary)	Blue	Brown
High voltage	Brown	Red
High voltage Center tap	Brown and black	Red and Yellow

Table 5-19: Old and new power transformer lead color codes

Chapter six

Diode Rectifier

Objectives

When you have studied this chapter, you should

- Be able to test and to identify diode polarity
- Have an understanding of the diode's one direction conduction processes
- Have an understanding of different types of rectifier, advantage and disadvantage of each type
- Have an understanding of the way to improve the rectifier's efficiency with smoothing capacitor
- Have an understanding of the diode specifications required for any rectifier
- Be able to design rectifier for any required specification and voltage

Further reading
Study aids for this chapter are available at
Lander, Cyril W. (1993). "2. Rectifying Circuits". Power electronics (3rd ed.). London: McGraw-Hill.

A rectifier is an electronic device that converts alternating current (AC) into direct current (DC). The process is known as rectification. Rectification is the conversion of alternating current (AC), which periodically reverses direction, to direct current (DC), which flows in only one direction. This involves a device that only allows one-way flow of electrons. This is exactly what a semiconductor diode does.

The input of rectify is an AC current that alternates in its nature. As result, the process of rectification alone produces a DC current that, though unidirectional, consists of pulses of current. Many applications of rectifiers, such as power supplies for radio, television and computer equipment, require a steady constant DC current (as would be produced by a battery). In these applications the output of the rectifier is smoothed by an electronic filter (usually a capacitor) to produce a steady current.

There are different forms of rectifiers including vacuum tube diodes, mercury-arc valves, copper and selenium oxide rectifiers, semiconductor diodes, silicon-controlled rectifiers and other silicon-based semiconductor switches. Rectifier circuits may be single-phase or multi-phase (three being the most common number of phases). Most low power rectifiers for domestic equipment are single-phase, but three-phase rectification is very important for industrial applications and for the transmission of energy as DC. In this chapter, we will describe different circuits' configurations of semiconductor diode rectifiers based around single phase.

Diode is a two-terminal electronic component which allows electrical current to flow in only one direction and blocks the flow in the opposite direction. Diode presents asymmetric transfer characteristic, with low (ideally zero) resistance to current flow in one direction, and high (ideally infinite) resistance in the other. Diodes may be regarded as one-way valves and they are used in various circuits, usually as a form of protection and rectification. There are different types of diode but their basic functions are the same. The figure 6-1 shows package and schematic symbol of diode.

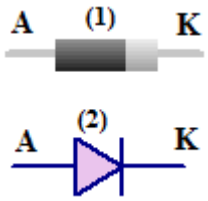


Figure 6-1: Diode device package (1) , diode Schematic symbol (2)

6. 1. Diode biasing

To bias a diode, we apply dc voltage across it. Mainly there are three methods of diode biasing: forward bias, reverse bias and zero bias. For zero bias no external dc voltage is applied to the diode thus in the following session we are going to discuss on the two first biasing methods.

- **Forward biasing**

Forward bias is the condition that permits the current to pass through the diode. A dc voltage must be connected in direction to forward-bias the *pn* junction. The negative terminal of the biasing dc source must be connected to the *n region (cathode)* and the positive terminal connected to the *p region (anode)*.

Experiment 6-1: Diode forward and reverse biasing

Connect the diode in the condition that allows the current to pass through the PN junction, a dc voltage source connected by conductive material across a diode in the direction to produce forward bias. This external bias voltage is designated as V (Bias or B_1). The resistor (lamp), limits the current to a value that will not damage the diode.

Part lists

No	Items	Specifications	Quantity
1	Voltmeter	Digital multimeter	1
2	Lamp	Lamp 9V-10W	1
3	Wire	22-gauge (0.33mm^2) solid wire	40cm
4	Breadboard	Prototyping board (RSR 03MB102)	1
5	Battery	9V dc supply	1
6	Diode	1N4001	1

When the anode (A) is positive and the cathode (K) is negative (though the load) current will flow through the load, the diode and back to the power supply battery (B_1). As diode is made from silicon, creates a voltage drop of approximately 0.6 to 0.75 Volts or more.

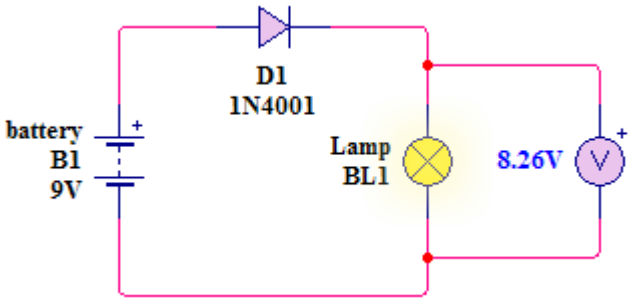


Figure 6-2: Diode forward biased current pass "Lamp ON"

The reading on voltmeter is the supply voltage minus voltage drop of the diode (9V-0.7V) and the circuit layout is shown in figure 6-3.

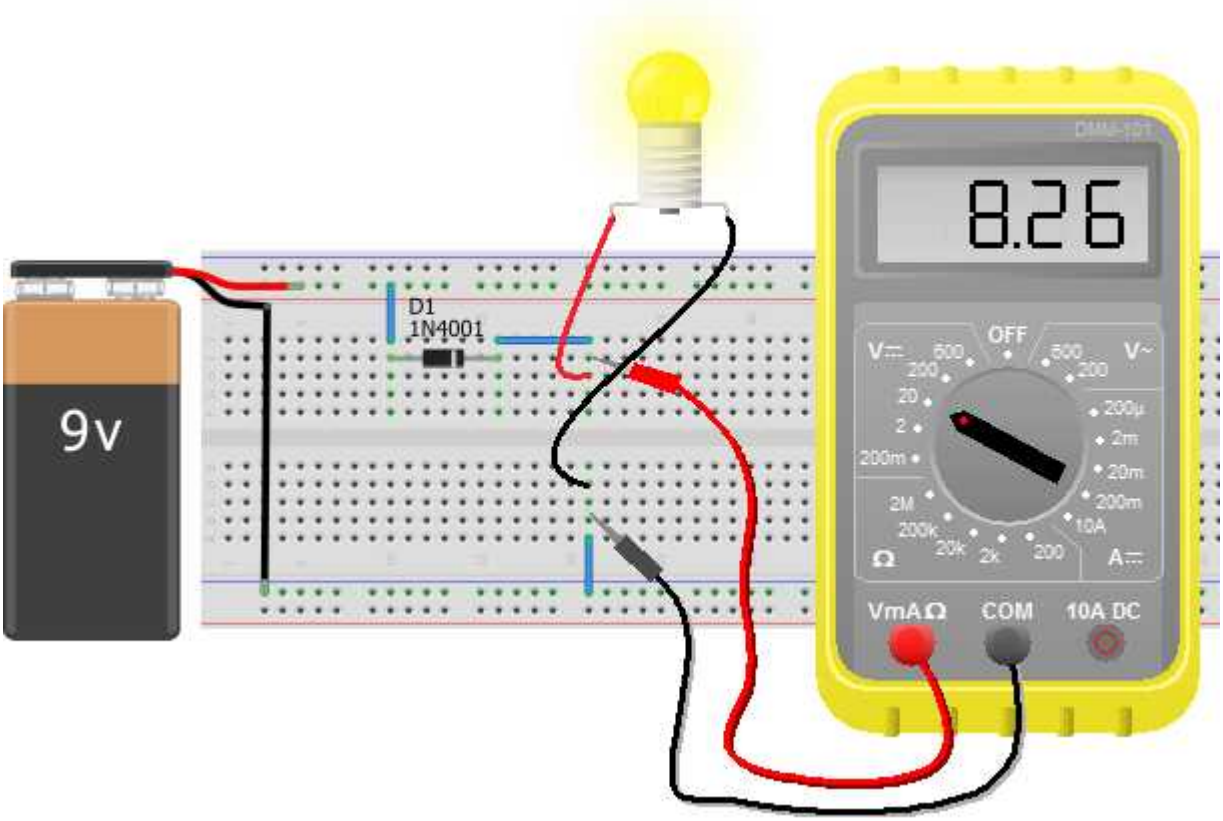


Figure 6-3: Diode forward biased and lamp ON, circuit connection

Forward Voltage Drop

Electricity uses up a little energy pushing its way through the diode, rather like a person pushing through a door with a spring. This means that there is a small voltage across a conducting diode, it is called the forward voltage drop and is about 0.7V for all normal diodes which are made

from silicon. The forward voltage drop of a diode is almost constant whatever the current passing through the diode so they have a very steep characteristic (current-voltage graph).

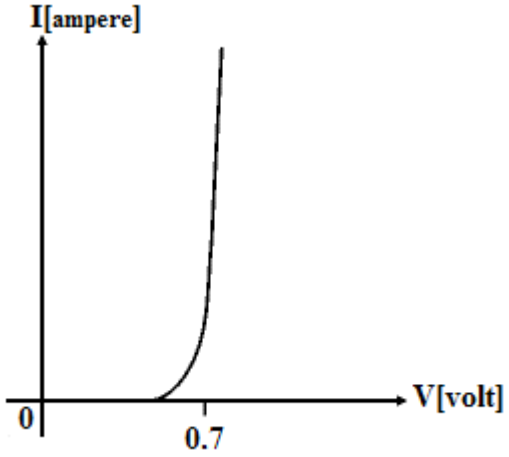


Figure 6-4: I/V silicon diode characteristics

- **Reverse bias**

When the cathode (K) of diode is connected at positive of power supply and Anode (A) to negative of power supply, the diode is said to be reverse biased. Actually no current flow through the load and voltage on the load goes across to zero (0 Volt).

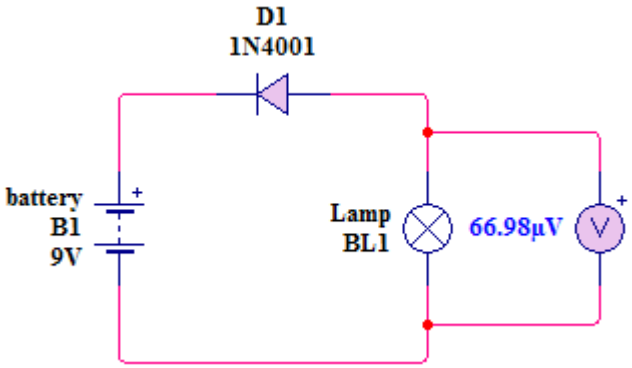


Figure 6-5: Diode Reverse biased no current pass "Lamp OFF"

When the anode (A) is negative and the cathode (K) is positive no current will flow through the load (lamp is OFF) therefore the reading on voltmeter is zero.

Normally, when a reverse voltage is applied to a perfect diode does not conduct, but all real diodes leak a very small current of a few µA or less. This can be ignored in most circuits because it will be very much smaller than the current flowing in the forward direction.

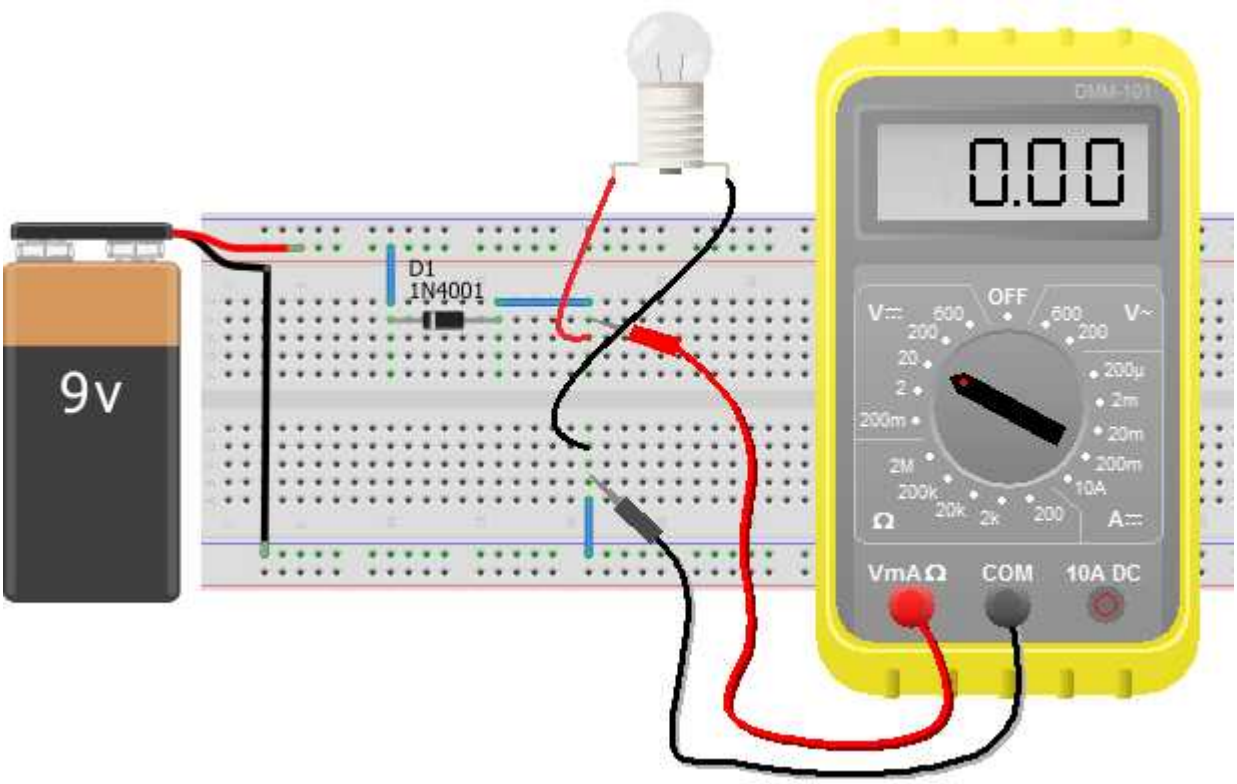


Figure 6-6: Diode reverse biased and lamp OFF, circuit connection

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However, all diodes have a maximum reverse voltage (usually 50 V or more) and if this is exceeded the diode will fail and pass a large current in the reverse direction, this is called breakdown. Ordinary diodes can be split into two types: Signal diodes which pass small currents in order of 100 mA or less and Rectifier diodes which can pass large currents.

6. 2. Diode testing (Anode and Cathode identification)

Apart of eye inspection on the white color which determine the location of cathode, diodes can be tested using a multimeter. It is normally the resistance of the diode in both forward and reverse directions that is tested. There are however a number of points to remember when testing diodes.

Being digital and analogue multimeters are suitable for diode testing, and in many cases will have a special "diode check" range usually marked with a diode symbol. This range is most often used when testing diodes or any other semiconductor device. The importance for this is that the meter tests the diode by applying a voltage across the diode junction. The normal voltages used by the meter on other resistance ranges will not be high enough to overcome the diode's forward junction potential and so will not make the diode conduct, even in the forward direction. This would give an indication that the diode was open circuit (very high resistance). If the diode range is used, the test voltage applied by the meter will be high enough to overcome the forward junction potential and the diode will conduct. Therefore in the forward direction (meter positive lead to the anode and black probe to cathode of diode) the diode's resistance can be measured. The actual value will vary from device to device and from meter to meter, so a precise value cannot be given. With a good silicon diode however, a reading in the forward direction of about 1kΩ could be expected, rather than germanium diodes.

With the meter leads reversed, an out of range (infinity) or open circuit reading (usually indicated by a display something like "1." on a digital meter) should be expected.

Experiment 6-2: Detemining diode polarity

Being able to determine the polarity (cathode versus anode) and basic functionality of a diode is a very important skills for the electronics technician. Normally a diode behaves like one-way valve for electricity; this implies that we should be able to verify its one-way working.

1st method: using ohmmeter

Part lists

No	Items	Specifications	Quantity
1	Ohmmeter	Digital multimeter	1
2	Diode	1N4001	1

When test a diode using Ohm's range, there are a number of things to remember:

- Make sure you are using the ohm (Ω) range.
- Using a digital meter, connect the black lead to the cathode and red to the anode (forward bias - around 1kΩ).
- Reverse the meter connections (reverse bias - infinity reading).

Note:

- If you are using an analogue meter the above polarities, on second point, are reversed.
- To determine which end of the diode is either the cathode or anode, you must know with sureness which test lead of the multimeter is positive and which is negative. With most digital multimeters, the red lead is used as positive and the black lead as negative.

Low resistance indicates forward bias when black lead is connected to the cathode and red lead to anode of diode.

Reversing leads shows high resistance tending to the infinity "1." indicating reverse bias. At this time the red lead is connected to the cathode and the black lead to the anode of the diode. Ohm-meter connected this way across the diode, it should show a very high resistance ("OL" on some digital meter models).

Beware that some digital multimeters equipped with a "diode check" function may output a very low test voltage (less than 0.3 volts) when set to the regular "resistance" (Ω) function: too low to fully collapse the depletion region of a PN junction. The reason behind is that the "diode check" function is to be used for testing semiconductor devices, and the "resistance" function for anything else. By using a very low test voltage to measure resistance, it is easier for a technician to measure the resistance of non-semiconductor components connected to semiconductor components, since the semiconductor component junctions will not become forward-biased with such low voltages.

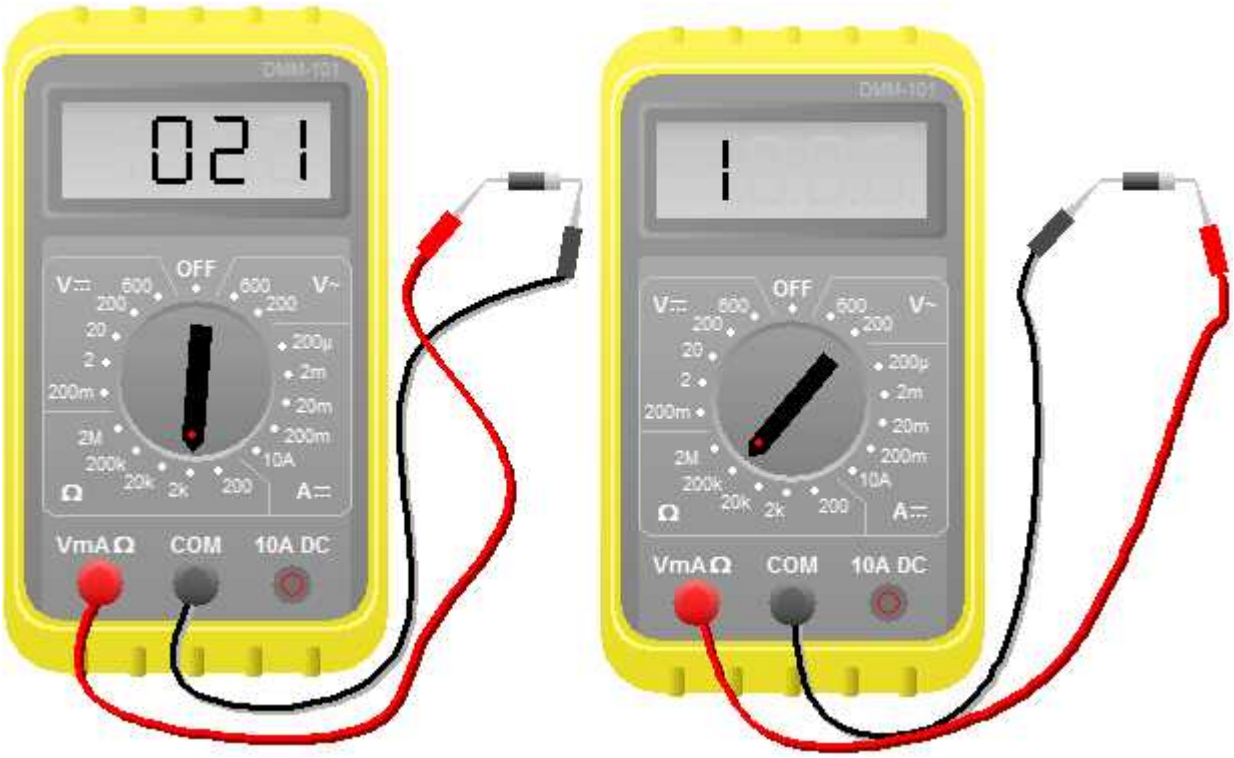

Figure 6-7: Determining the diode polarities using ohmmeter

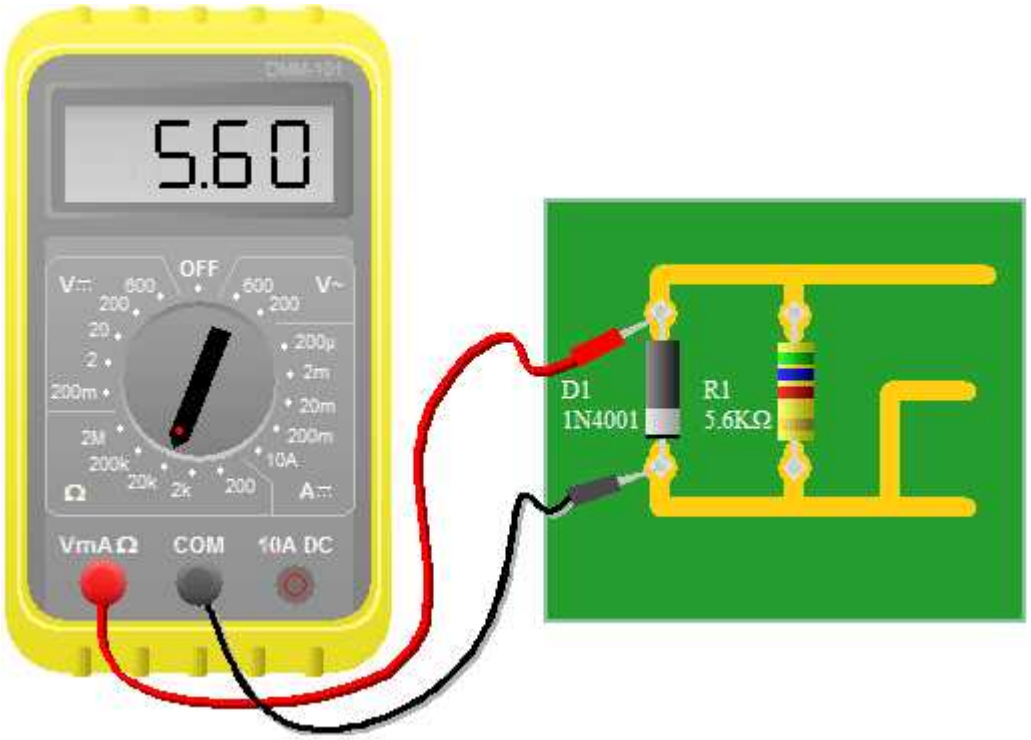

Figure 6-8: Testing Diode in a circuit

Consider the example of a resistor and diode connected in parallel, soldered in place on a printed circuit board (PCB), as shown in figure 6-8. Normally, one would have to unsolder the resistor

from the circuit (disconnect it from all other components) before measuring its resistance, otherwise any parallel-connected components would affect the reading obtained. When using a multimeter which outputs a very low test voltage to the probes in the "resistance" function mode, the diode's PN junction will not have enough voltage impressed across it to become forward-biased, and will only pass negligible current. Consequently, the meter "sees" the diode as an open (no continuity), and only registers the resistor's resistance.

Ohmmeter equipped with a low test voltage (less than 0.7 V) does not see the diode allowing it to measure parallel resistors.

If such ohmmeter were used to test a diode, it would indicate a very high resistance (many kilo-ohms) even if connected to the diode in the "correct" (forward-biased) direction. It is better to check the multimeter's battery since the battery fail can lead to wrong value reading.

2nd method: using multimeter's diode check

For the reason mentioned above, some digital multimeter manufacturers equip their meters with a special "diode check" function which displays the actual forward voltage drop of the diode in volts, rather than a "resistance" figure in ohms. These meters work by forcing a small current through the diode and measuring the voltage dropped between the two tests leads.

Part lists

No	Items	Specifications	Quantity
1	Diode tester	Digital multimeter with diode test function	1
2	Diode	1N4001	1

Meter with a "Diode check" function displays the forward voltage drop of 0.613 volts instead of a low resistance.

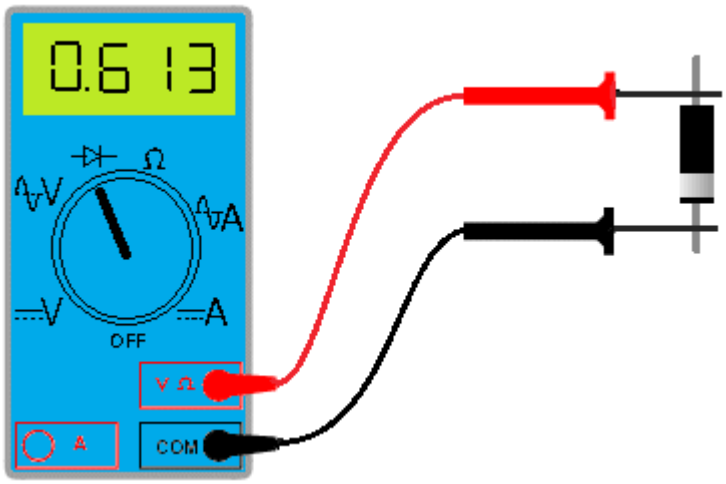

Figure 6-9: Determining diode polarities by using diode check function

The forward voltage reading obtained with such a meter will typically be less than the "normal" drop of 0.7 volts for silicon and 0.3 volts for germanium, because the current provided by the meter is of trivial proportions.

3rd method: using DC supply

This method is used when a multimeter with diode-check function is not available, or you would like to measure a diode's forward voltage drop at some non-trivial current.

Part lists

No	Items	Specifications	Quantity
1	Voltmeter	Digital multimeter	1
2	Diode	1N4007	1
3	Resistor	68Ω	1
4	Battery	AA cell Battery (2) or 3V DC Supply	1
5	Breadboard	Prototyping board (RSR 03MB102)	1

Connecting diode in the forward bias, anode to the positive and cathode to the negative terminal of the battery, the voltmeter reads the diode voltage drop of about 0.6V to 0.7V.

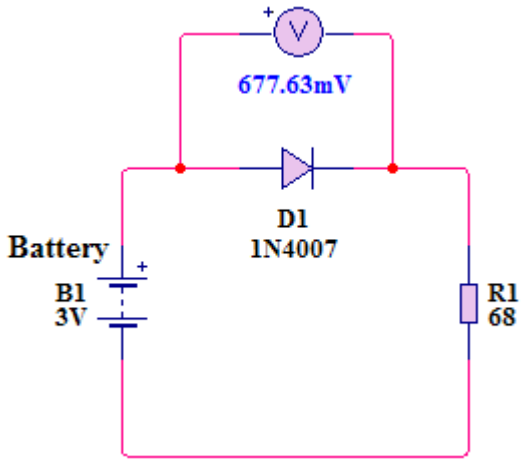

Figure 6-10: Determining diode polarity by using forward DC voltage, voltmeter indicates diode voltage drop of about 0.7V

But on other hand, connecting the diode backwards to this testing circuit will simply result in the voltmeter indicating the full voltage of the battery.

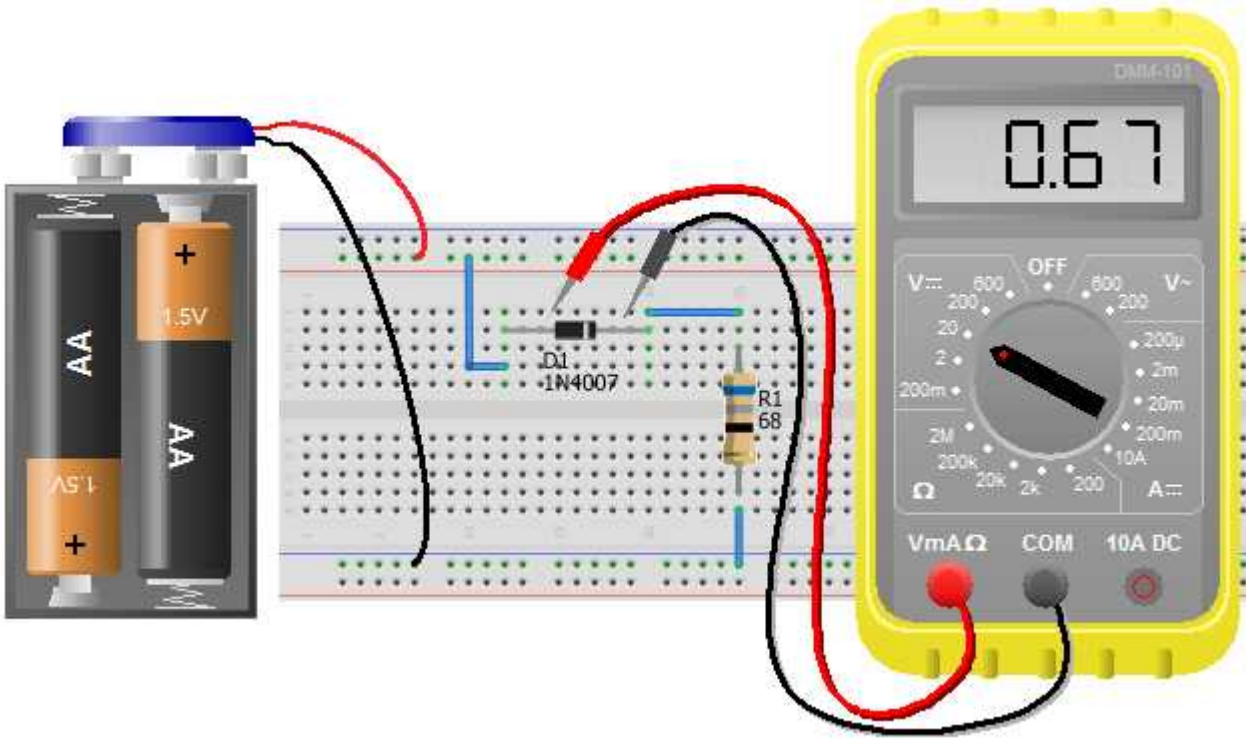

Figure 6-11: Circuit connection for determining diode polarity by using forward DC voltage, voltmeter reads diode voltage drop of about 0.7 V

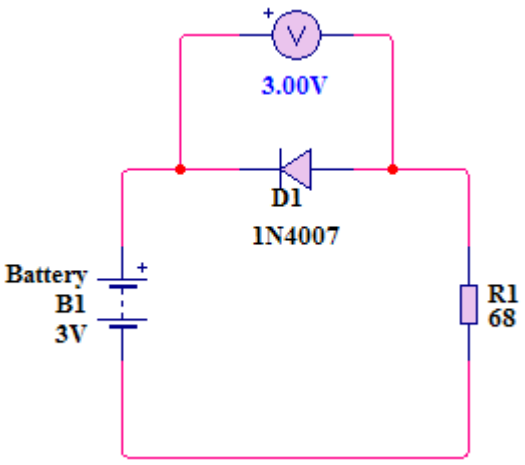

Figure 6-12: Determining diode polarity by using reverse DC voltage, voltmeter indicates supply voltage

Hands on tip

A special type of diode that makes use of the depletion region capacitance is the *varactor*. It is used as variable capacitor in which the capacitance is controlled by the reverse-bias voltage. By increasing or decreasing the reverse voltage, you can increase or decrease the capacitance.

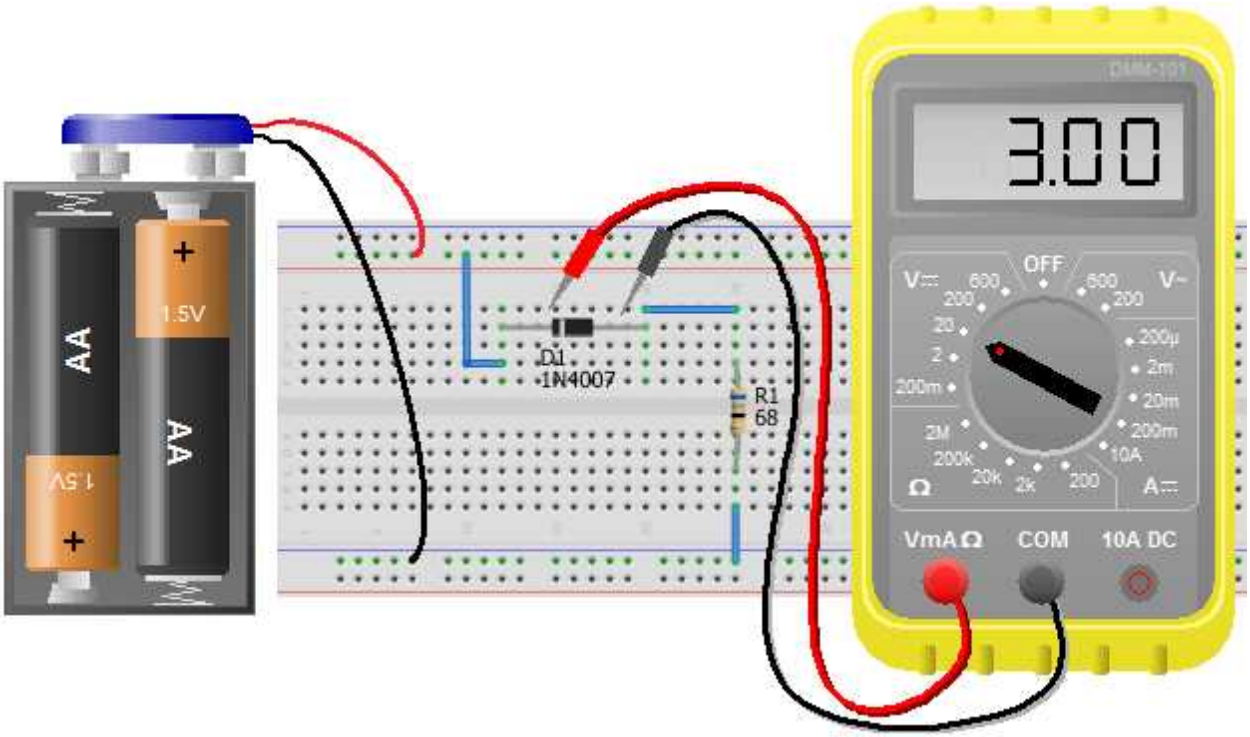

Figure 6-13: Circuit connection for Determining diode polarity by using reverse DC voltaget, voltmeter indicates supply voltage

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6. 3. Rectifiers

A rectifier is an electronic circuit that converts alternating current (AC), which periodically reverses direction, to direct current (DC), which flows in only one direction. The process is known as rectification. Most of electronic devices use DC or direct current. A diode is a solid-state device which has the action of allowing the current to flow in only one direction from an alternating current and this form a rectifier circuit. There are a number of different configurations of diode rectifier circuit that can be used. These different configurations each have their own advantages and disadvantages, and are therefore applicable to different applications.

6. 3. 1. Half Wave Rectifier

A half wave rectifier is an electronic circuit which converts the incoming Alternating Current (AC) input power into a Direct Current (DC) output power by just blocking one half cycle of each complete sine wave and allows through the other. This is the simplest form of rectifier which often uses only a single diode.

The primary of the transformer (VP1) is connected to the AC supply. This induces an ac voltage (VS) across the secondary of the transformer. During the positive half cycle of the input voltage the polarity of the voltage across the secondary forward biases the diode.

Half Wave Rectifier Circuit Principle

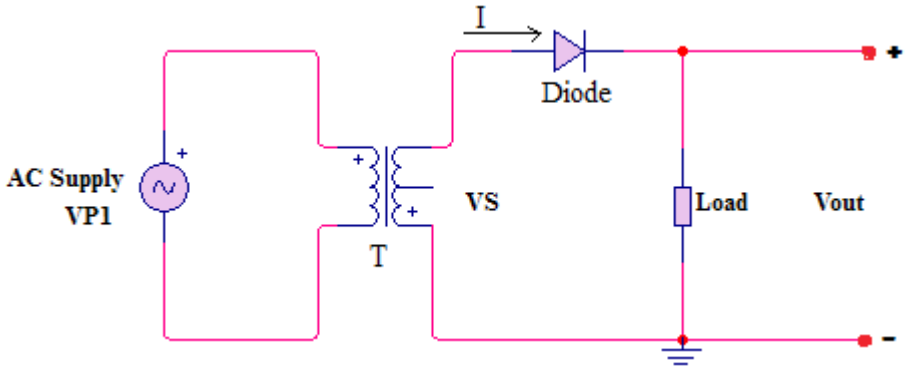


Figure 6-14: Half Wave Rectifier Circuit

The output voltage waveform is pulsed since at negative half cycle the diode is in reverse and does not allow the current to follow through the load. The input and output voltages waveforms are shown in figure 6-15.

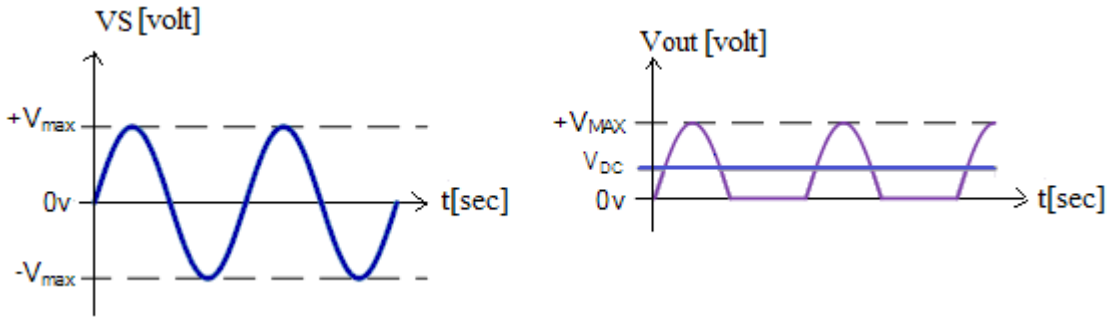


Figure 6-15: Half Wave Rectifier waveform

Working Principle of the Half Wave Rectifier

During each "positive" half cycle of the AC sine wave, the diode is forward biased as the anode is positive with respect to the cathode resulting in current flowing through the diode, load resistor and back to the supply.

During each "negative" half cycle of the AC sinusoidal input waveform, the diode is reverse biased as the anode is negative with respect to the cathode. Therefore, no current flows through the diode or circuit. Then in the negative half cycle of the supply, no current flows in the load resistor as no voltage appears across it, therefore $V_{out} = 0$.

When the DC load is resistive, the current flowing in the load resistor is proportional to the voltage, and the voltage across the load resistor will therefore be the same as the supply voltage.

The current on the DC side of the circuit flows in one direction only making the circuit unidirectional. Thus, the load resistor receives from the diode a positive half of the waveform, zero volts, a positive half of the waveform, zero volts, etc.

The equivalent DC voltage, V_{DC} across the load resistor is calculated as follows:

The value of the voltage across the load resistor is equal in value to an equivalent DC voltage of $0.318 \times V_{max}$ of the input sinusoidal waveform or $0.45 \times V_{rms}$ of the input sinusoidal waveform.

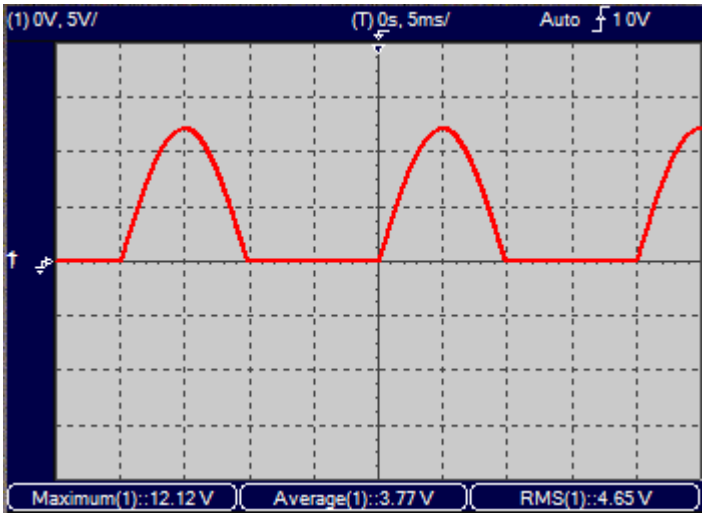


Figure 6-16: Halfwave rectifier waveform pictured from oscilloscope

$$V_{dc} = V_{max}/\pi = 0.318V_{max} = 0.45Vs$$

Where:

V_{max}: The maximum or peak voltage value of the AC sinusoidal supply,

V_S : The RMS (Root Mean Squared) value of the supply,

V_{dc}: The DC voltage of the output of rectifier.

Experiment 6-3: Half wave Rectifier

Design a half wave rectifier with 9V as input voltage and 220 Ω as load resistor. Calculate the peak input voltage $V_{in(max)}$ and the output voltage V_{dc} applied on load resistor. By using oscilloscope measure the output voltage and compare it with what you have calculated.

Part lists

No	Items	Specifications	Quantity
1	Oscilloscope	Agile oscilloscope 54622D	1
2	Diode	1N4001	1
3	Resistor	220 Ω	1
4	9VAC supply	Agilent Function generator 33120A	1
5	Breadboard	Prototyping board (RSR 03MB102)	1
6	Wire	22-gauge (0.33mm^2) solid wire	40cm

The sinusoidal input supply voltage V_1 is connected to CH1 of the oscilloscope while the output voltage is connected to CH2 of the oscilloscope.

$$V_{max} = (V_{in} * \sqrt{2}) - 0.7V$$
$$= (9V * 1.414) - 0.7V = 12.0279V$$

$V_{R1} = V_{dc} = V_{max}/\pi$

$= 12.0279V/3.14 = 3.83V$

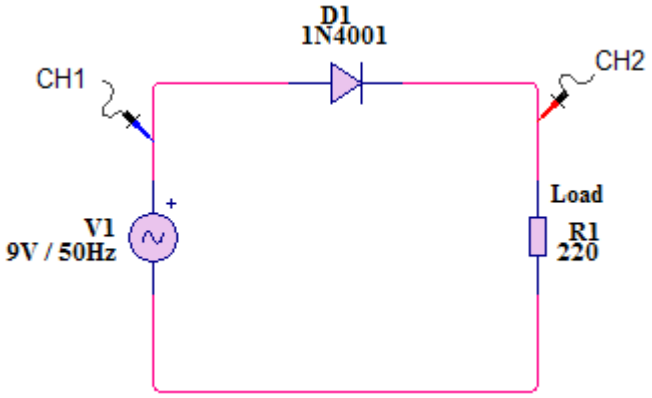


Figure 6-17: Half wave rectifier circuit

Procedure and Working Principle

During the positive half cycle of the input voltage the diode is forward biased and the current is diverted to the load. On the other hand, the negative half cycle of the input voltage the polarity of voltage gets reversed as a result, the diode is reverse biased.

Practically when diode is reversed biased no current flows through the circuit and almost no voltage is developed across the resistor. All input voltage appears across the diode itself, thus the current will flow only in the positive half-cycle (0 to 180 degrees) and the diode will shut-off during the negative half-cycle from 180 degrees to 360 degrees. The period of a sine wave from 0 degrees to 360 degrees equals the inverse of the input frequency ($1/F_{in}$).

In the case of 50 Hertz it is: 1/50 = 20 mSec.

This implies that when the input voltage is going through its positive half cycle, output voltage is almost the same as the input voltage despite the diode voltage drop and during the negative half cycle no voltage is available across the load. This explains the unidirectional pulsating dc waveform obtained as output. This is why we get very poor power transfer with the diode off during the negative half-cycle and the positive half-cycle changing constantly between zero volts and peak. Note that Vmax is equal to Vpeak .

Principally when rectifying an alternating voltage we wish to produce a “steady” and continuous DC voltage free from any voltage variations or ripple. One way of doing this is to connect a large value Capacitor across the output voltage terminals in parallel with the load resistor as shown below. This type of capacitor is known commonly as a “Reservoir” or Smoothing Capacitor.

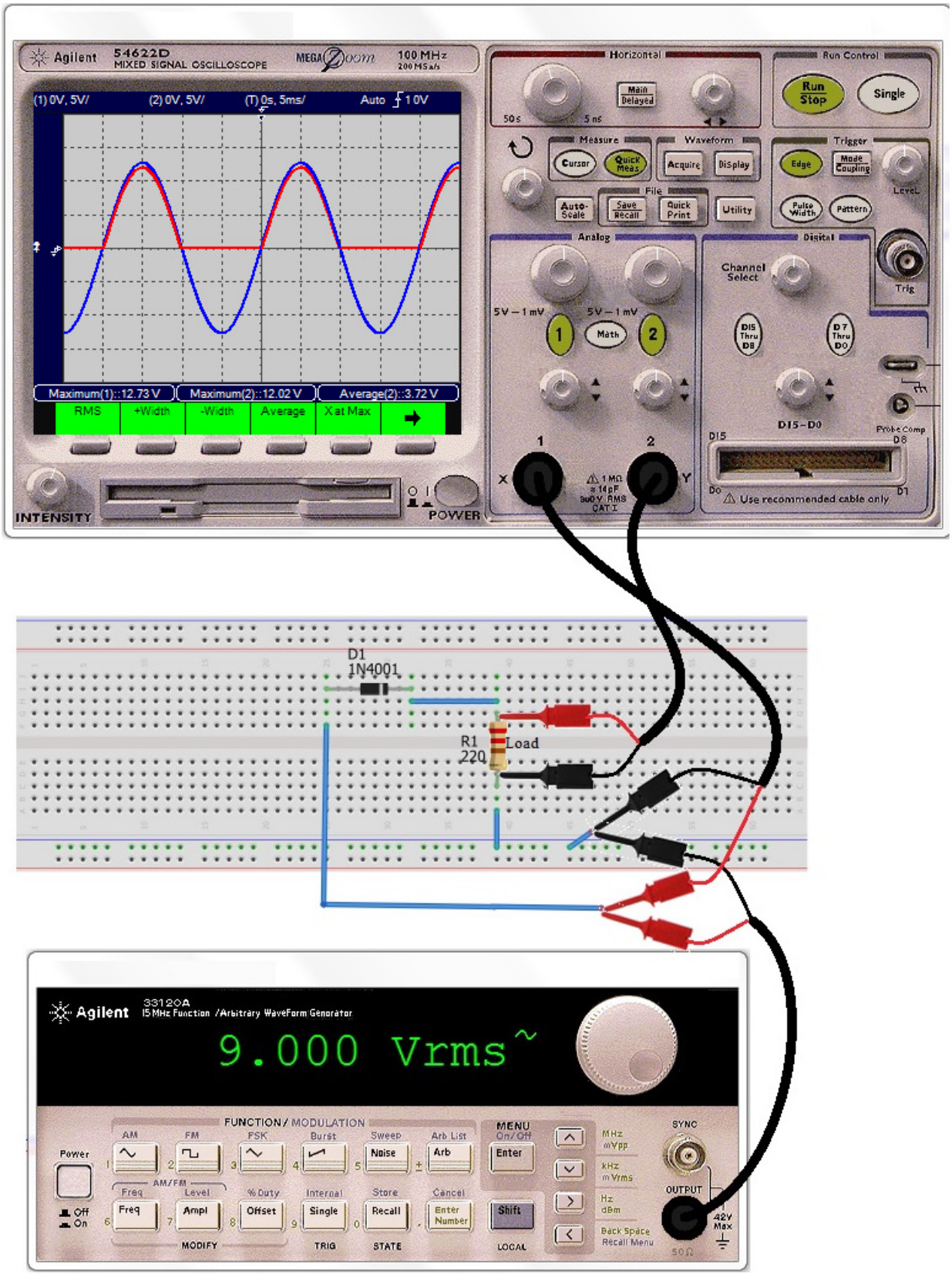


Figure 6-18: Half wave rectifier circuit connection

Half wave Rectifier with Smoothing Capacitor

During the positive first quater-cycle of the input, the diode is forward-biased, allowing the capacitor to charge to approximately the diode drop of the input peak. When the input begins to decrease below its peak, the capacitor retains its charge and the diode becomes reversed-biased.

During the remaining part of the cycle, the capacitor can discharge only through the load resistance at a rate determined by the $R_L C$ time constant. The larger the time constant, the less the capacitor will discharge.

A word of caution.

When constructing these circuits observe capacitor polarity and diode polarity. The voltage ratings of the capacitors should exceed the expected peak voltage by 50%.

Also note the current ratings of the transformers and diodes.

Experiment 6-4: Half wave rectifier with smoothing capacitor

Design a half wave rectifier with 9V as input voltage and 220 Ω as load resistor and insert the capacitor in parallel with load. Calculate the peak input voltage $V_{in(max)}$ and the output voltage V_{dc} applied on load resistor without capacitor. Insert a capacitor and measure V_{out} using oscilloscope.

Part lists

No	Items	Specifications	Quantity
1	Oscilloscope	Agile oscilloscope 54622A	1
2	Diode	1N4001	1
3	Resistor	220 Ω	1
4	9VAC supply	Agilent Function generator 33120A	1
5	Breadboard	Prototyping board (RSR 03MB102)	1
6	Wire	22-gauge (0.33mm^2)solid wire	40cm
7	Capacitor	47µF/50V	1
8	Capacitor	470µF/50V	1

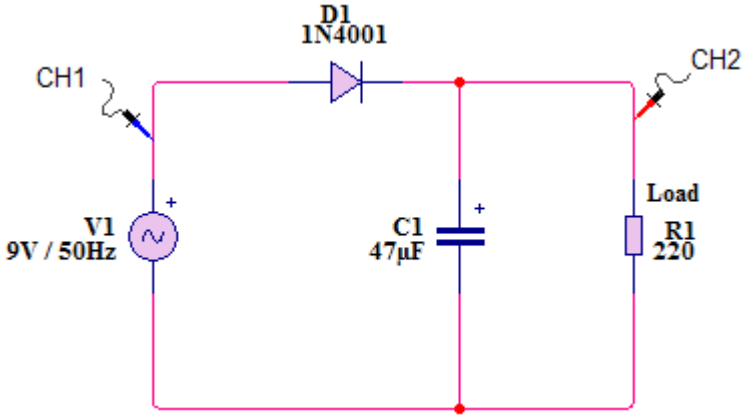


Figure 6-19: Half wave Rectifier with Smoothing Capacitor

In figure 6-19, we inserted a 47 µF/50V capacitor across the load. The capacitor charges during the positive half-cycle, then discharges through the load during the negative half-cycle since no current flow through the diode. The amount of ripple is dependent on the resistance of the load and the value of the capacitance used.

A small capacitor produces a number of ripples or a low resistance load (drawing high current thus less time for the capacitor to discharge) will not be reduce enough the level of ripples because the capacitor has less time to discharge.

A larger capacitor produces less ripples or a higher resistance load (drawing less current thus enough large time for the capacitor to discharge) will reduce the level of ripple because the capacitor has sufficient time to discharge. With no load at all, just the capacitor and the rectifier, the capacitor will charge to peak and will hold the charges until it gets the load to discharge through. The resulting waveform is shown in figure 6-20.

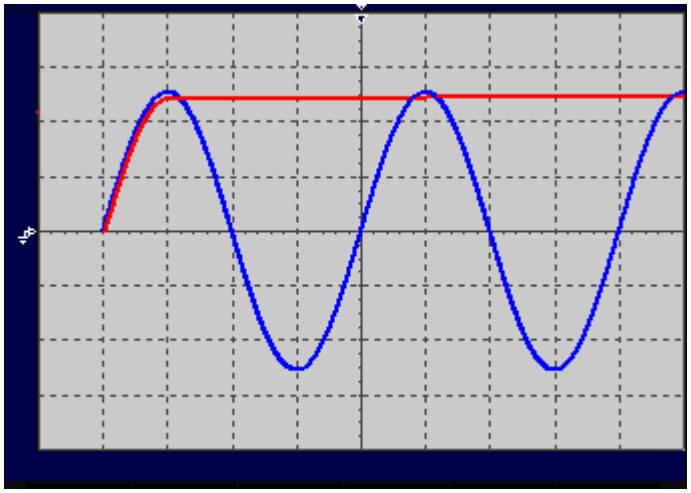


Figure 6-20: Waveform of Half wave Rectifier with smoothing capacitor and with high or removed load resistance

When rectification is used to provide a direct voltage power supply from an alternating source, the amount of ripple can be further reduced by using larger value capacitors but there are limits both on cost and size. For a given capacitor value, a greater load current (smaller load resistor) will discharge the capacitor more quickly (*RC* Time Constant) and so increases the ripple obtained. Replace capacitor with low capacitance (47 µF) with a capacitor of large capacitance (470 µF) as shown in the circuit figure 6-22.

Hands on tip

A diode is sometimes used to isolate two power sources such as in the case of a battery backup for a computer system. The power from the power supply is connected through a series diode to the power input point on the system. A battery backup system is connected to the same point through its own series diode. The battery backup is set for s slightly lower voltage so that it does not discharge the battery during normal operation. When a power failure occurs, the battery backup system takes over and the diodes prevent the two power sources from affecting each other.

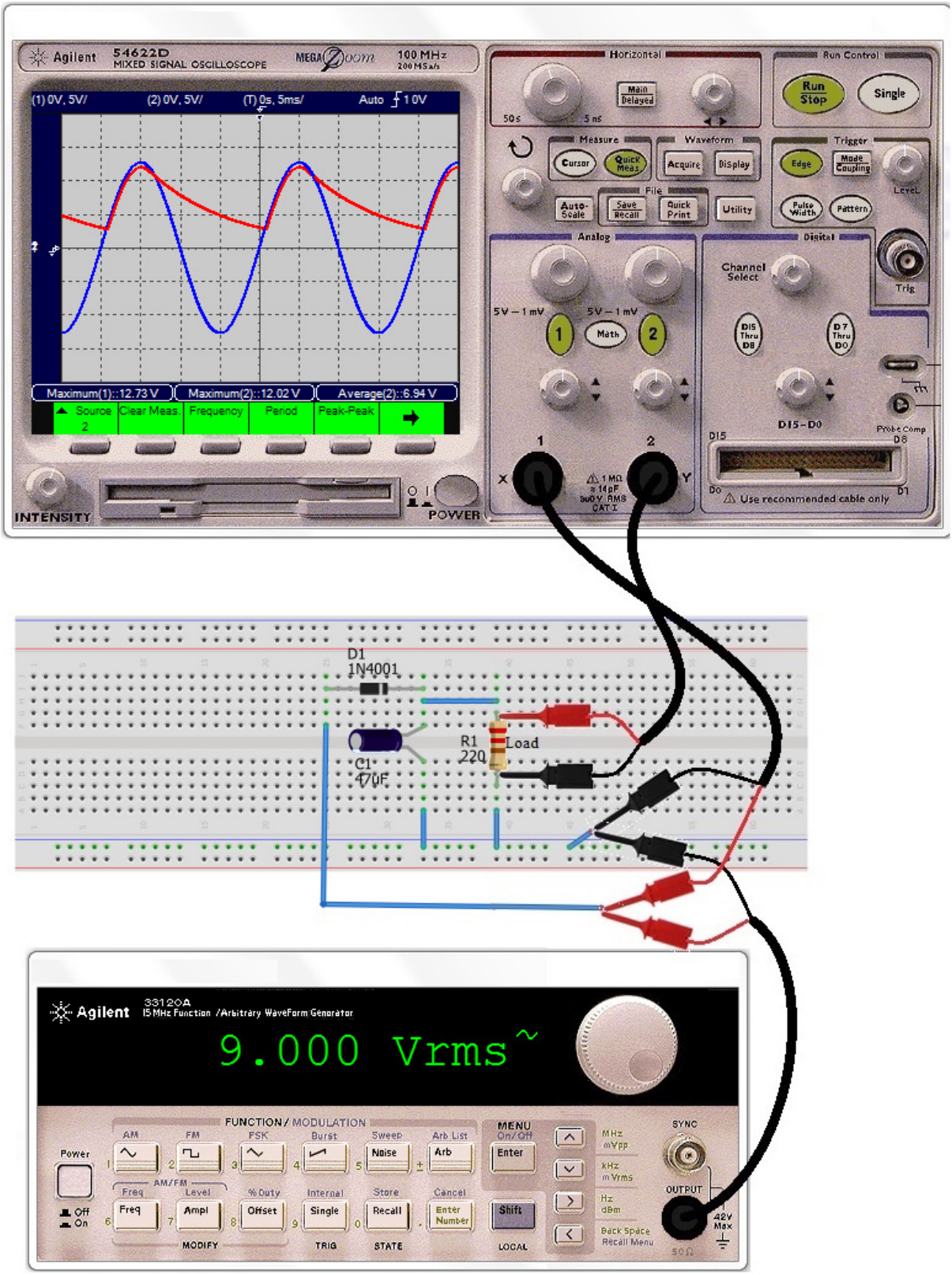


Figure 6-21: Half wave Rectifier with Smoothing Capacitor, circuit connection

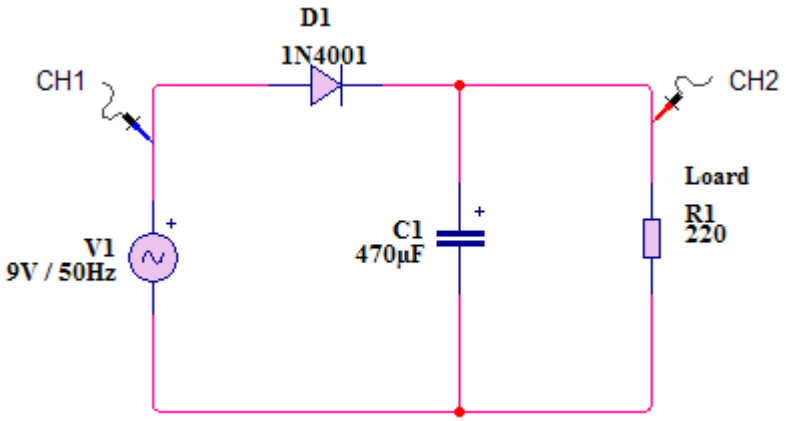


Figure 6-22: Circuit for Half wave rectifier with a large capacitor

Even if the amount of ripples is reduced notwithstanding that are not removed completely to get a steady direct current. This is caused by excess of ripples of a single phase half wave rectifier. The resulting improvement of the output waveform is shown on the oscilloscope figure 6-23.

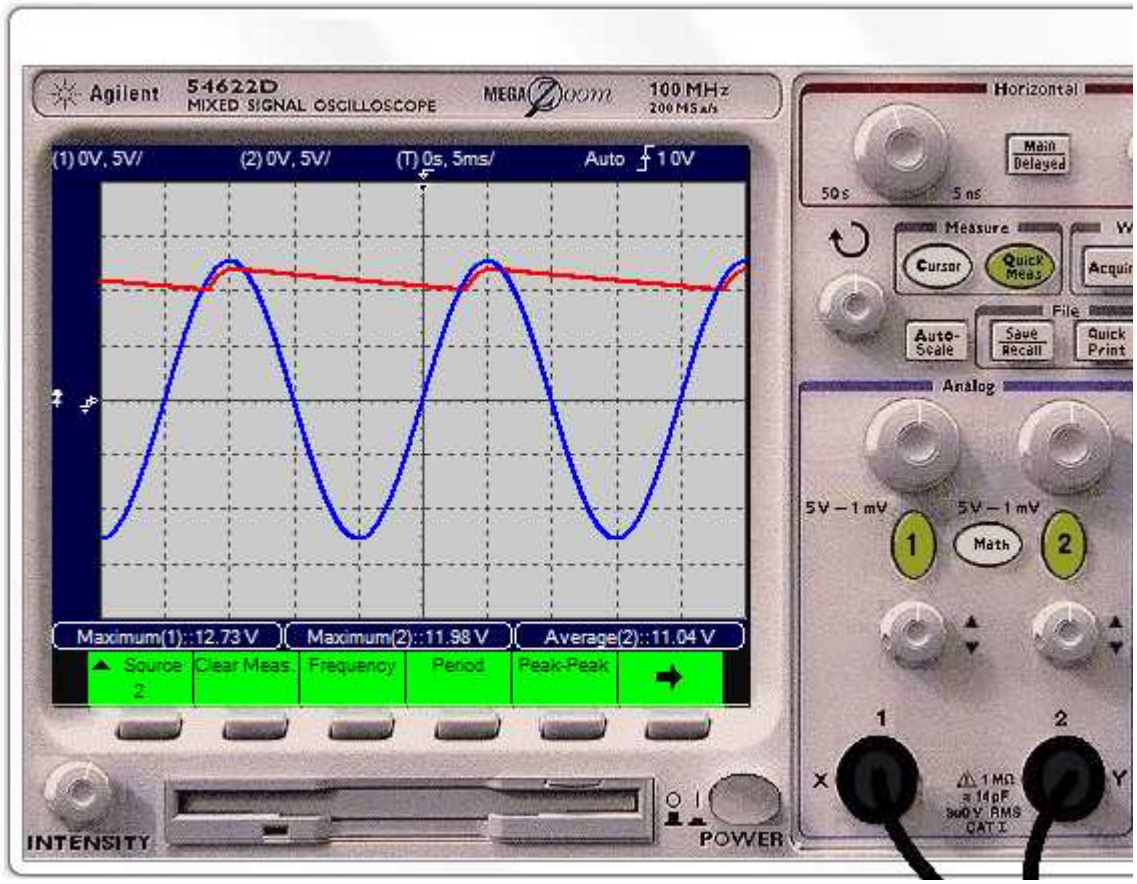


Figure 6-23: Half wave rectifier with a large capacitor waveform

In practice, the half-wave rectifier is most used in low-power applications because of their major disadvantages. The output amplitude is less than the input amplitude, there is no output during the negative half cycle so a half of the power is wasted and the output is pulsed DC resulting in exces-

sive ripple. To overcome these disadvantages a number of Power Diodes are connected together to produce a Full Wave Rectifier as discussed in the next tutorial.

Even though the capacitor is made high to reduce the ripples, the output voltage represents changes (ripples) which are not convenient to the electronic equipments like computer, printer, TV, etc.. This leads to the use of a bridge rectifier (Full-wave rectifier).

The advantage of this circuit is its simplicity; the drawback is the fact that there is long interval between successive peaks of the rectified signal. This makes smoothing less effective and more difficult to achieve high level ripple rejection.

Half wave Rectifier Advantage and Disadvantage

Although, the half wave rectifier circuit may not provide the level of performance needed for many applications, it is the most straightforward rectifier circuit that can be used in rectification. Some of the advantages and disadvantages of half wave rectifier are described in table 6-1.

Advantage	Disadvantage
• Simplicity in design since it uses only one diode	• Excess of voltage variation and the output is pulsed.
	• The output voltage is less than the input voltage; there is no output during the negative half cycle so the half of the power is wasted.
	• Requires large capacitor for smoothing which is expensive and big size.

Table 6-1: Advantage and disadvantages of half wave rectifier

6. 3. 2. Full Wave Rectifier

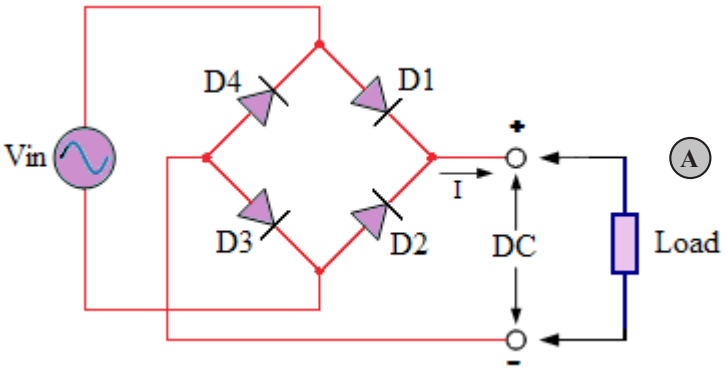
Full-wave rectification is an electronic circuit which converts incoming AC current power into a DC output power by making use of both polarities (positive and negative half cycle) of the input waveform. Mainly there are two forms of full wave rectifier circuit that can be used; the full wave bridge rectifier and the two diodes full wave with a centre tapped transformer. Each type has its own features and is suited for different applications.

- **The Full Wave Bridge Rectifier**

The full wave bridge rectifier circuit uses four diodes in configuration that looks like a bridge and is most often called Graëtz Bridge. This type of rectifier is more widely used nowadays. It offers a more efficient use of the transformer as well as not requiring a centre tapped transformer.

Full Wave Bridge Rectifier Circuit Configurations

Often four diode bridges can be bought as single items, making construction of the overall circuit much simpler but their discrete construction is based on four diodes arrangement. The basic circuits are outlined in figure 6-24:



Or

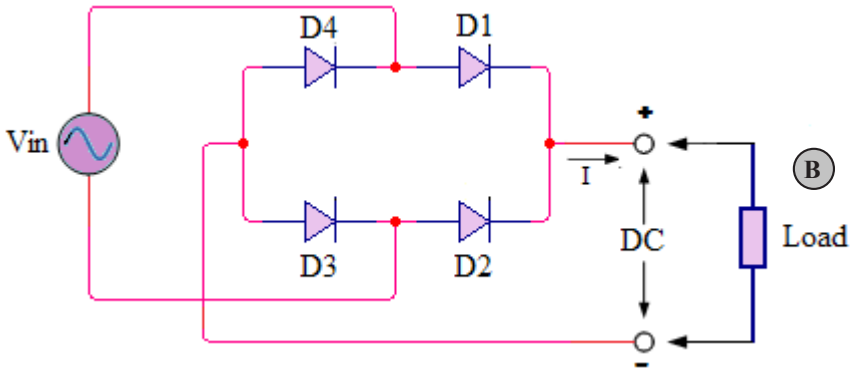


Figure 6-24: (A) and (B), Full wave bridge rectifier schematic circuits

Working Principle of the Circuit

The four diodes labeled D_1 to D_4 are arranged in "series pairs" with only two diodes conducting current during each half cycle.

The Positive Half-cycle

During the positive half cycle of the supply, diodes D_1 and D_3 conduct in series while diodes D_2 and D_4 are reverse biased and the current flows through the load as shown below. The arrows show conventional current flow.

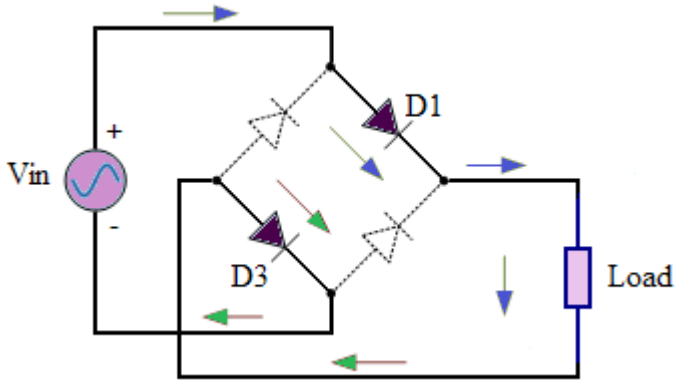


Figure 6-25: Diodes of full wave bridge rectifier working during the positive half-cycle of AC supply

The Negative Half-cycle

During the negative half cycle of the supply, diodes D_2 and D_4 conduct in series, but diodes D_1 and D_3 switch "OFF" as they are now reverse biased. The current flowing through the load is the same direction as before.

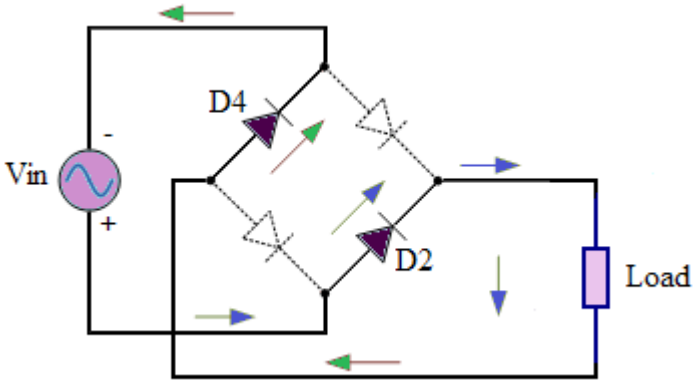
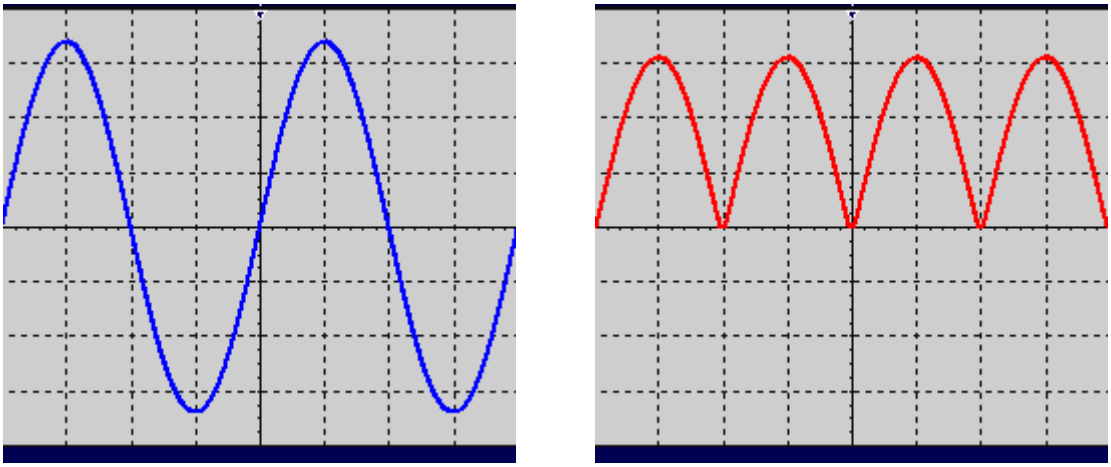


Figure 6-26: Diodes of full wave bridge rectifier working during the negative half-cycle of AC supply

As the current flowing through the load is unidirectional, so the voltage developed across the load is also unidirectional. The resulting waveform is shown in figure 6-27.

Hands on tip

When you view pulse waveforms on an oscilloscope, set the scope to be DC coupled, not AC coupled. The reason is that AC coupling places a capacitor in series and can cause distortion in low-frequency pulse signals. Also, DC coupling allows you to observe the dc level of the pulse.



(**b**) (**b**)

Figure 6-27: Input waveform (a) and output of full wave bridge rectifier waveform (b)

The average DC voltage across the load is calculated as follow:

$$V_{dc} = V_{av} = (2V_{max})/\pi = 0.637V_{max}$$

However in reality, during each half cycle the current flows through two series diodes instead of just one so the amplitude of the output voltage is two diode voltage drops (2 x 0.7 = 1.4V) less than the input $V_{IN(max)}$ amplitude. It can be seen from the waveforms, that the fundamental frequency within the rectified waveform is twice that of the source waveform, there are twice as many peaks in the rectified waveform. The ripple frequency is now twice the supply frequency (e.g. 100Hz for a 50Hz supply).

Bridge output voltage: As shown, the two diodes are always in series with the load resistor during both the positive and the negative half-cycles. Neglecting the barrier potential of the two diodes, the output voltage is a full-wave rectified voltage with a peak value equal to the peak secondary voltage of transformer once used.

$$V_{peak(out)} = V_{peak(seccondary)}$$

Although we can use four individual power diodes to make a full wave bridge rectifier, pre-made bridge rectifier components are available "off-the-shelf" in a range of different voltage and current sizes that can be soldered directly into a PCB circuit board or be connected by spade connectors.

Experiment 6-5: Full wave bridge rectifier

Full wave bridge rectifier uses four individual rectifying diodes connected in a closed loop called "bridge" configuration to generate the desired output. The bridge rectifier circuit does not require a special centre tapped transformer, thereby reducing its size and cost. The single secondary winding is connected to one side of the diode bridge network and the load to the other side. Design a DC supply based on full wave rectifier capable to produce 7VDC on its output terminal. In experiment, the secondary winding voltage of transformer is replaced by a function generator and the part list is given below.

Part lists

No	Items	Specifications	Quantity
1	Oscilloscope	Agile oscilloscope 54622D	1
2	Diode	1N4001	4
3	Resistor	1.5KΩ, 1/2watt	1
4	Function generator	Agilent Function generator 33120A	1
5	Breadboard	Prototyping board (mini board)	1
6	Connecting wire	22-gauge (0.33mm^2) solid wire	40cm

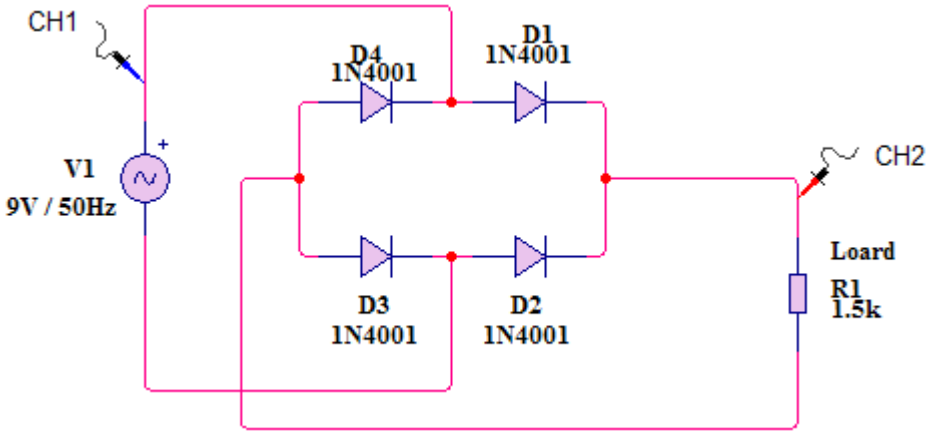


Figure 6-28: Full wave bridge rectifier circuit

Procedure and Working principle

In the figure 6-28, D_1 and D_3 conduct during the positive half-cycle while D_2 and D_4 conduct during the negative half-cycle. Power delivered here is twice that of half-wave rectification because we are using both half-cycles.

Using 9 volts AC, we have 9 X 1.414 or 12.726 volts peak, (12.726 volts).

The peak on load resistor is the two diode voltage drop less than the peak input voltage (12.726-1.4) that is 11.326Volts. Now to get the average we multiply the peak (11.326 volts) by 0.637 which equals 7.23 volts, double that of half-wave.

Hands on tip

When connecting protoboard circuits, always consistently use standard colors for universal connections such as signals, power supply voltage, and ground. For example, you can use green wires for signals, red wires for power supply voltage, and black wires for ground connection. This helps you identify wiring during connecting and troubleshooting.

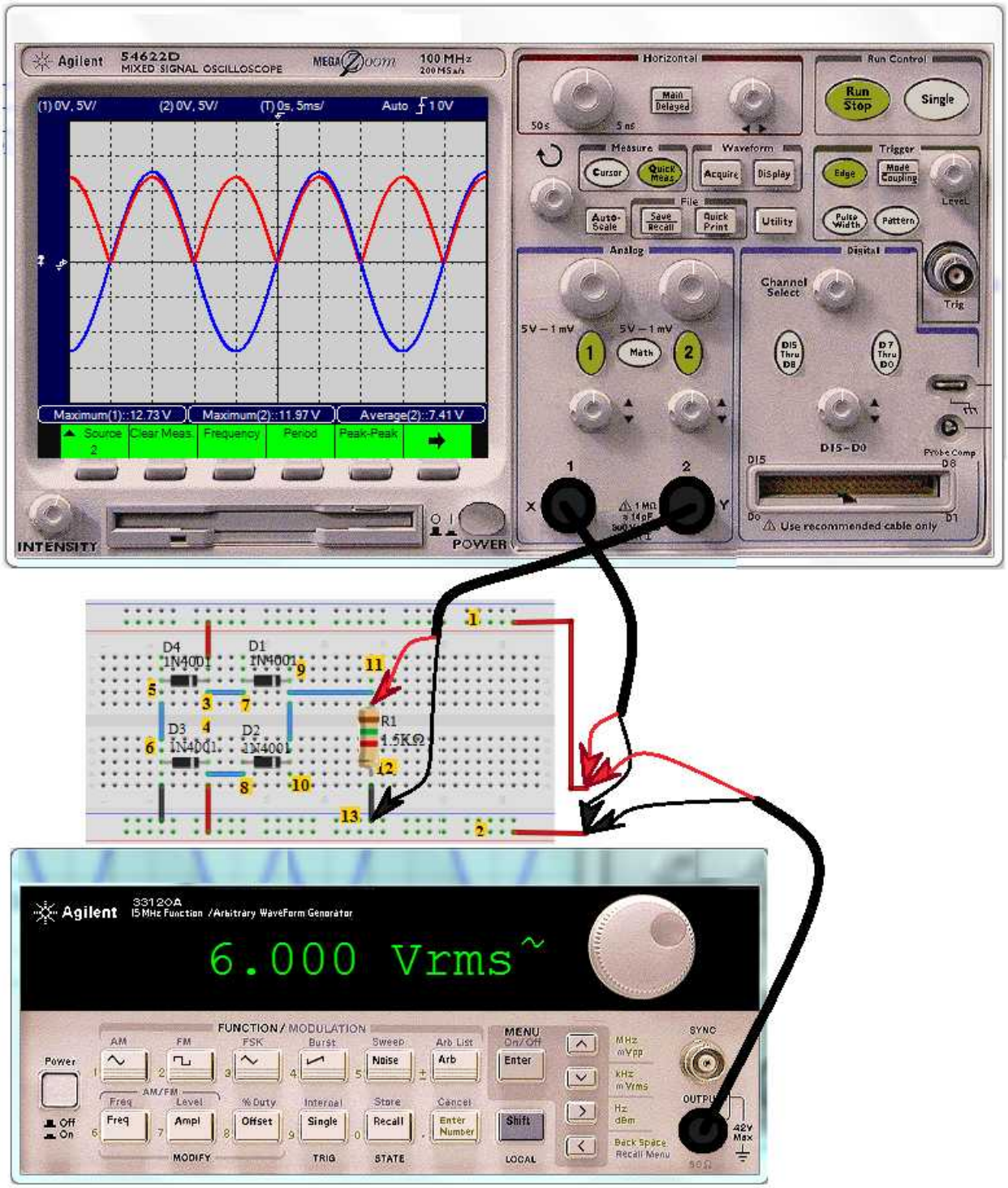


Figure 6-29: Full wave bridge rectifier, circuit connection

It should be noted that when this circuit is constructed the voltage on the meter will be about one volt lower. This is due to a 0.7 volt drop across the diodes, meter calibration due to the frequency change (from 50 Hz to 100 Hz), and calculation errors.

The Full Wave Bridge Rectifier with a Smoothing Capacitor

The full-wave bridge rectifier gives us a greater mean DC value (0.637 V_{max}) with less superimposed ripple while the output waveform is twice that of the frequency of the input supply frequency. We can use a smaller filter capacitor to clean out the ripple than we used with half-wave rectification. We can therefore increase its average DC output level even higher by connecting a suitable smoothing capacitor across the output of the bridge circuit as shown in figure 6-30.

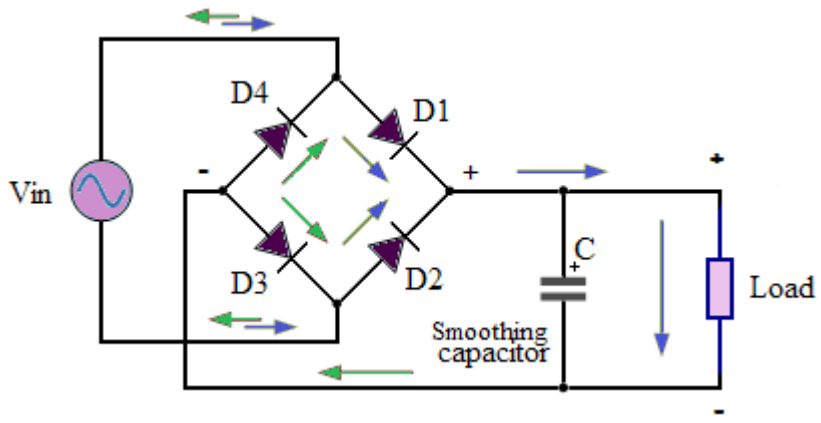


Figure 6-30: Full wave rectifier with a smoothing capacitor circuit principle

Experiment 6-6: Full wave bridge rectifier with filtering capacitor

To smooth the output of the rectifier a reservoir capacitor is used and placed across the output of the rectifier and in parallel with the load. This capacitor charges up when the voltage from the rectifier rises above that of the capacitor and then as the rectifier voltage falls, the capacitor provides the required current from its stored charge. The capacitor used must be able to handle the output voltage of a rectifier. This implies that a voltage rating of a capacitor is greater than $V_{DC.}$ The part list is given below.

Part lists

No	Items	Specifications	Quantity
1	Oscilloscope	Agile oscilloscope 54622D	1
2	Diode	1N4001	4
3	Function generator	Agilent Function generator 33120A	1
4	Breadboard	Prototyping board (mini board)	1
5	Wire	22-gauge (0.33mm^2)solid wire	50cm
6	Resistor	1.5kΩ	1
7	Capacitor	47μF/50V	1
8	Capacitor	100μF/50V	1

When capacitor charges up as the supply voltage rises the only way discharge path for the capacitor, apart from internal leakage is through the load to the rectifier or smoothing system. The diodes prevent backflow through the supply system such as transformer or function generator.

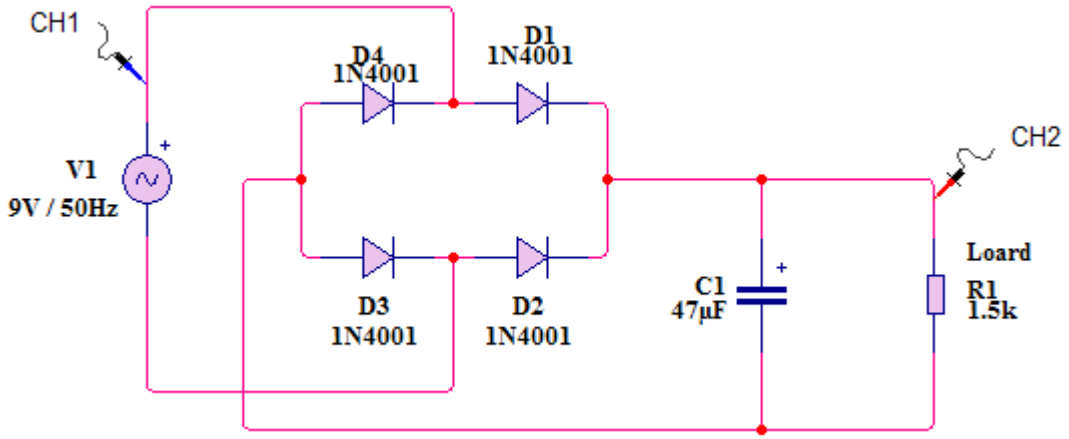


Figure 6-31: Full wave bridge rectifier with a smoothing capacitor

By inserting 47µF/50V capacitor in parallel with the load resistor, the amount of voltage variation is reduced but this voltage variation can still cause malfunction to the digital system which requires a steady current. The resulting circuit and waveform are shown in figure 6-32.

Full Wave Rectifier with a Large Capacitance

The resulting voltage waveform with 47µF capacitor does not fulfill the desired direct current form. On the discharge cycle of the smoothing capacitor, the capacitor needs to replace all the lost in ripple voltage up to the next charging with less as possible between the maximum and the following charging start. But it can only achieve this when the voltage from the rectifier exceeds that from the smoothing capacitor. This only occurs over a short period of the cycle. Consequently the current during this period is much higher. The large the capacitor, the better it reduces the ripple and the shorter the charge period.

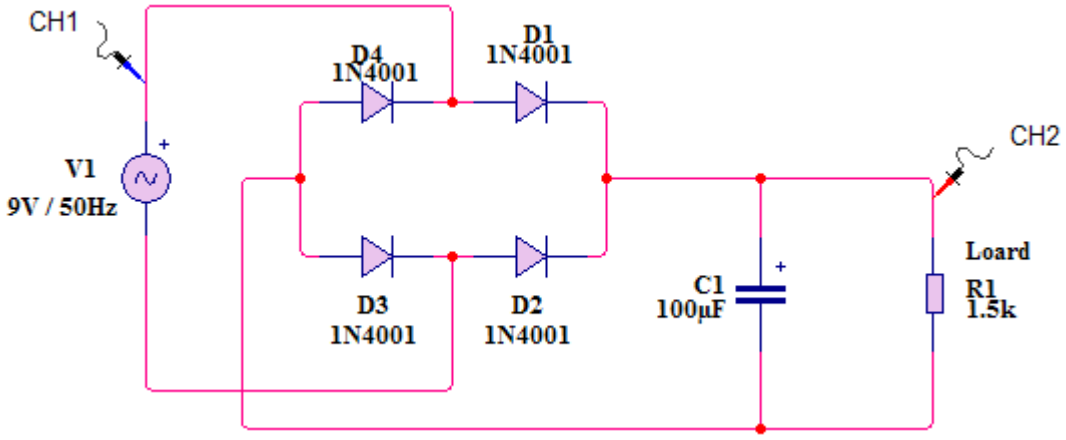


Figure 6-32: Full wave bridge rectifier with a large capacitor

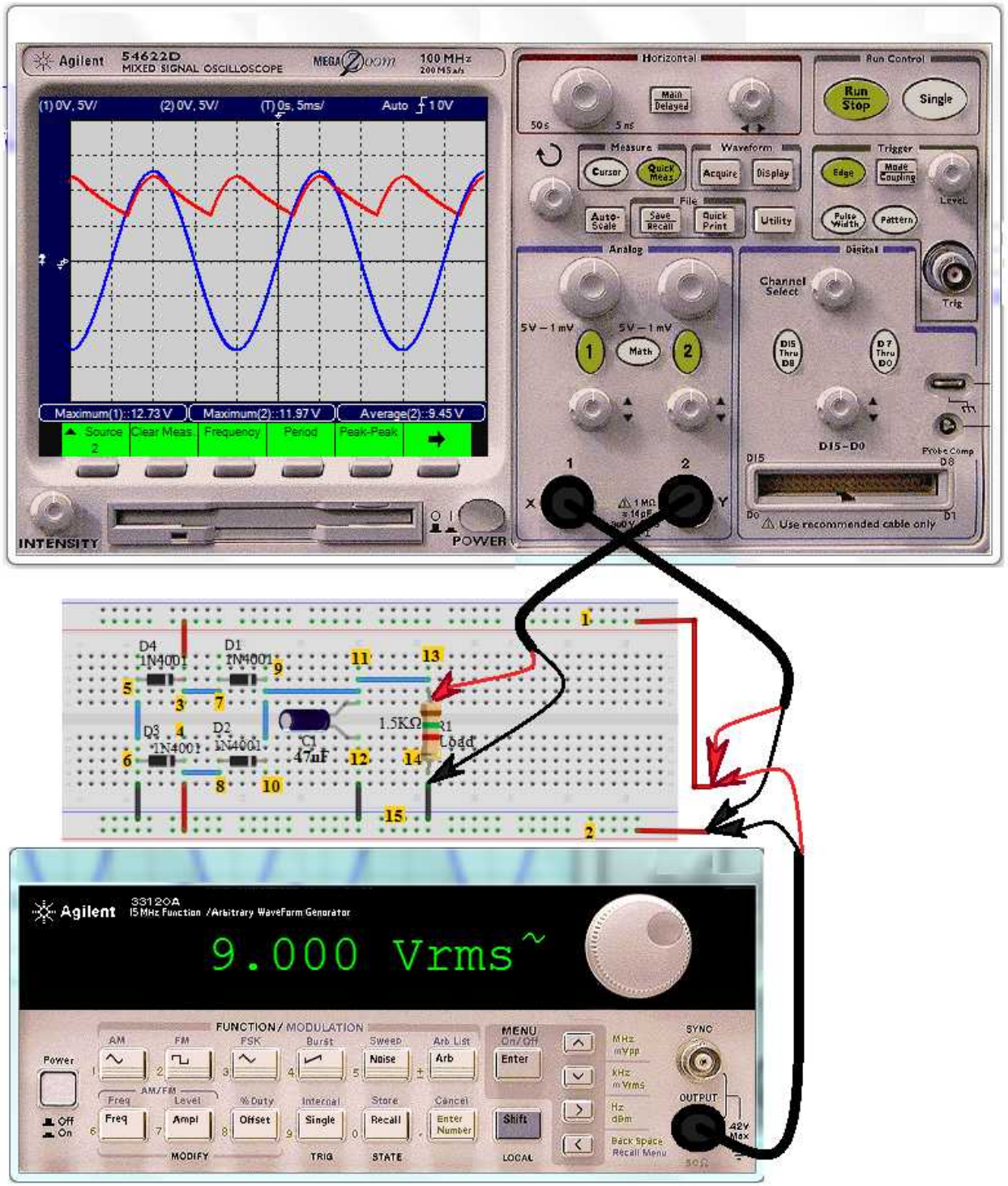


Figure 6-33: Full wave bridge rectifier with a smoothing capacitor circuit connection

By increasing a large filtering capacitor value, up to 100µF/50V, the signal becomes almost steady and the average output voltage is increased as shown in figure 6-34.

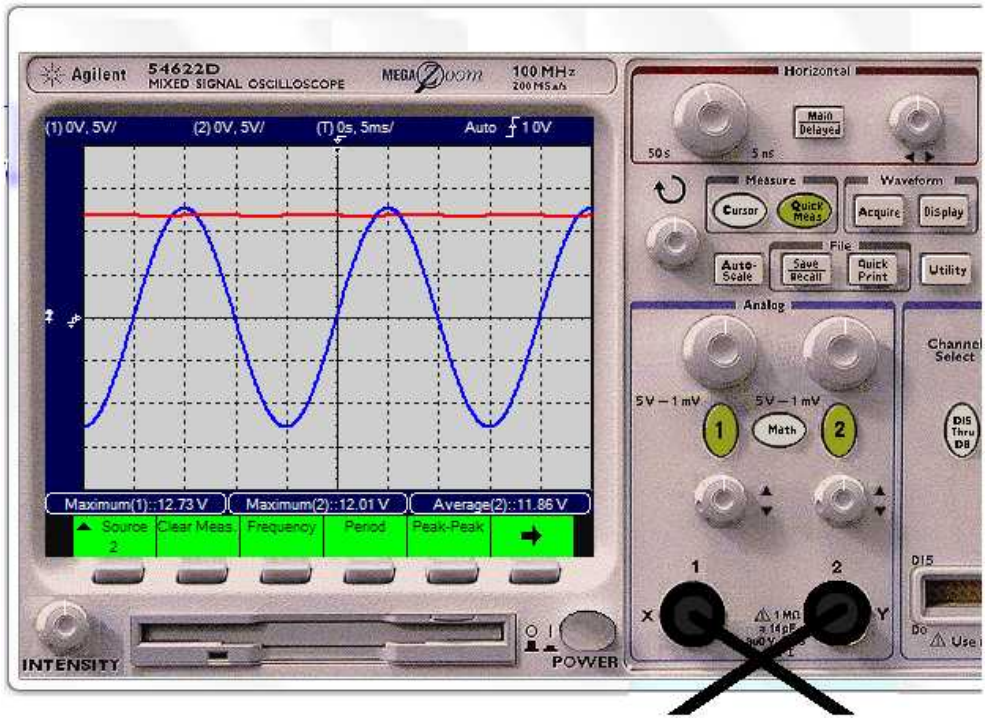


Figure 6-34: Full wave bridge rectifier with a large capacitor waveform

Warning:

- Do not attempt to measure both the AC voltage on the secondary winding and the output voltage across the load resistor at the same time. You could create a ground loop that could destroy one of the rectifier diodes.
- Electrolytic capacitors are polarized. Pay attention to their polarity to avoid possible injury to you or to others and to avoid destruction of the device.

Full Wave Bridge Rectifier Advantages and Disadvantages

Even though the full wave rectifier circuit requires more diodes than a half wave rectifier circuit, it has advantages in terms of utilizing both halves of the alternative input current waveform to provide the output.

Advantages	Disadvantages
• Utilizes both positive and negative waves of the AC waveform of the input current	• More complicated than half wave rectifier
• Requires small smoothing capacitor	• The twice frequency hum on an audio circuit may be more audible
• The output voltage is almost equal to the input voltage despite the diode voltage drop	
• Utilizes the whole secondary winding voltage of a transformer	

Table 6-2: Advantages and disadvantages of full wave bridge rectifier

Two-Diode Full Wave Rectifier

The two-diode full wave rectifier is an electronic circuit which converts the input AC current into a DC output current by using center tapped transformer. The two-diode full wave rectifier circuit was widely used in the days of thermionic valves or vacuum tubes because it only required the use of two diodes as a rectifier circuit using four valves would be large, the two diode version was much more preferable. These could be encapsulated in one device, thereby reducing cost and size. The basic full wave rectifier circuit using two diodes and a centre tapped transformer is shown in figure 6-35.

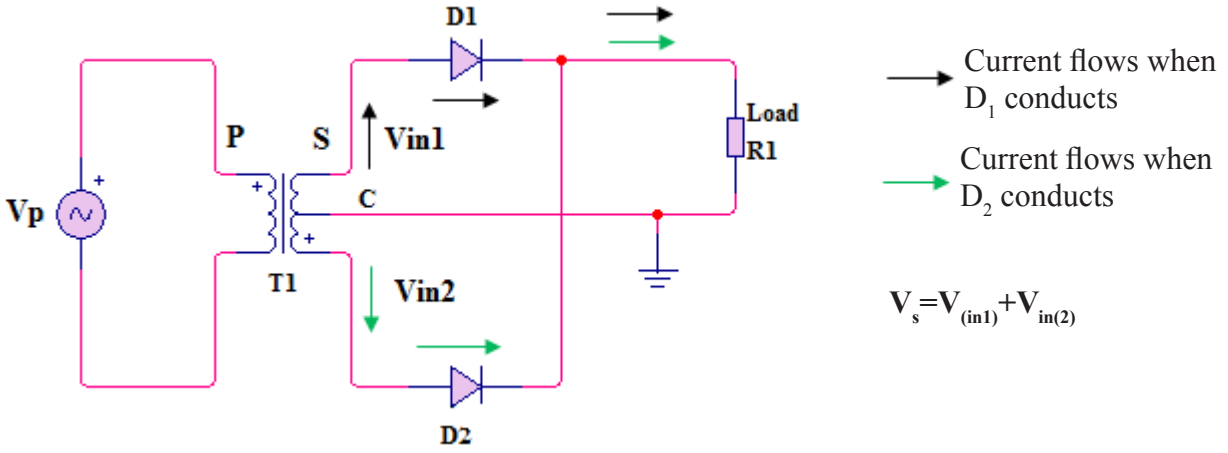


Figure 6-35: Two-diode full wave rectifier circuit principle using centre tapped transformer

This circuit, figure 6-35, uses two diodes, D_1 and D_2 , and it does need a center tapped transformer. The current flow within the circuit is represented by arrows in the above circuit diagram. This is useful in seeing how the circuit operates and how it is not as efficient in terms of usage of the transformer. Looking at the current flow diagram, it can be seen that current each half of the secondary winding is only used of half the cycle. This makes for very inefficient use of the transformer in terms of cost and resources.

Working Plinciple of the Circuit

The primary of the transformer is connected to AC supply system. This induces the current in the secondary winding with voltage corresponding to the ratio of number of turns of the primary to the secondary winding.

$$V_s = N_s/N_p * V_p$$

Where:

V_s: Secondary winding voltage

V_p: Primary winding voltage

N_s: Number of turns of the secondary winding

N_p: Number of turns of the primary winding

The induced secondary voltage has the same frequency of the primary and is split into $V_{in(1)}$ and $V_{in(2)}$ with the common centre tapped connection. Each diode conducts in turn when its anode terminal is positive with respect to the transformer centre point *C* producing an output during both half-cycles.

This full wave rectifier circuit consists of two power diodes connected to a single load resistance (R_L) with each diode taking it in turn to supply current to the load.

At positive half cycle, anode of D_1 is positive with respect to point *C* of a center tap, diode D_1 conducts in the forward direction as indicated by the arrows. At negative half cycle, anode of D_2 is positive with respect to point *C*, diode D_2 conducts in the forward direction and the current flowing through resistor R_1 is in the same direction for both half-cycles. As the output voltage across the load resistor R_1 is the phasor sum of the two waveforms combined, this type of full wave rectifier circuit is also known as a "bi-phase" circuit. The average DC output voltage across the load resistor is double of the single half-wave rectifier circuit and is about $0.637V_{max}$ of the peak voltage, assuming no losses.

$$V_{dc} = 2\,V_{max}/\pi$$
$$= 0.637\,V_{max}$$
$$= 0.9\,V_{rms}$$

Where:

V_{max}: The maximum peak value in one half of the secondary winding and

V_{rms}: The root mean square value measured in one half of the secondary winding.

Experiment 6-7: Two diodes full wave rectifier using centre tapped transformer

The two diodes full wave rectifier requires the use of center tapped transformer and two power diodes as well. This type of rectifier gives a great mean output voltage with respect to the half wave rectifier. Design a DC supply capable to replace 3x1.5V cell batteries of a radio. List of items to conduct experiment on it is provided below.

Part lists

No	Items	Specifications	Quantity
1	Oscilloscope	Agile oscilloscope 54622D	1
2	Diode	1N4007	2
3	Resistor	1KΩ	1
4	Transformer	Center taped transformer 220/6-0-6; 50Hz	1
5	Breadboard	Prototyping board (RSR 03MB102)	1
6	Connecting wire	22-gauge ($0.33mm^2$) solid wire	40cm

A 220VAC/12VAC center tapped transformer is to be pluged to a 220VAC outlet. Normally a 12VAC of the secondary winding of a center tapped transformer splite into two equal voltages. This signifies that the root mean square to the rectifier input side is 6V.

At the positive half cycle, D_1 is forward biased while D_2 is in reverse, therefore the current passes through the load resistor R_1 back to the center tap.

At negative half cycle, D_2 is forward biased and D_1 is in reverse, the current pass through the load resistor back to the center tap of a transformer as a result the unidirectional dc waveform obtained as output with twice the frequency of input. The circuit arrangement on breadboard is shwon in figure 6-37.

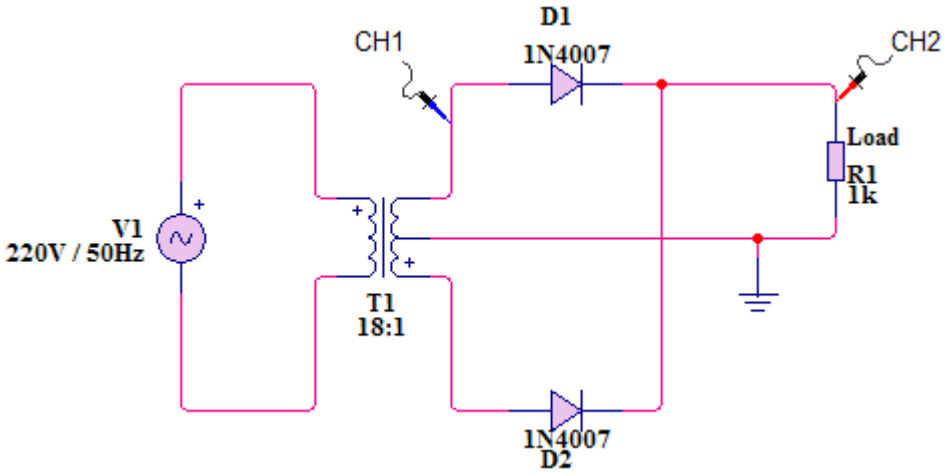


Figure 6-36: Two diodes full wave rectifier circuit using centre tapped transformer

The oscilloscope should be AC coupled to read the input waveform but should be DC coupled to read the output waveform.

The channel one of oscilloscope is connected to the input of the diode rectifier while the channel one is connected on the terminal of a load resistor. The peak value of the output rectifier diode is 7.9V and the average voltage (V_{dc}) on load resistor is 4.87V.

Remember that diode voltage drop has to be taken in consideration in calculations. Normally diode voltage drop varies between 6.5 and 7.5. A $6V_{rms}$ without diode voltage drop gives:

$$V_{max} = 6*\sqrt{2}$$
$$= 8.484V$$

With taking in account the diode voltage drop:

$$V_{max} = (6*\sqrt{2})-0.7$$
$$= 7.784V$$

The average voltage is given by:

$$V_{dc} = 2\,V_{max}/\pi$$
$$= 0.637*7.784 = 4.96\,V_{(rms)}$$

Note: The theory results differ a little bit to the practical results as it was shown in the above experiments. The reason behind is the use of imperfect devices.

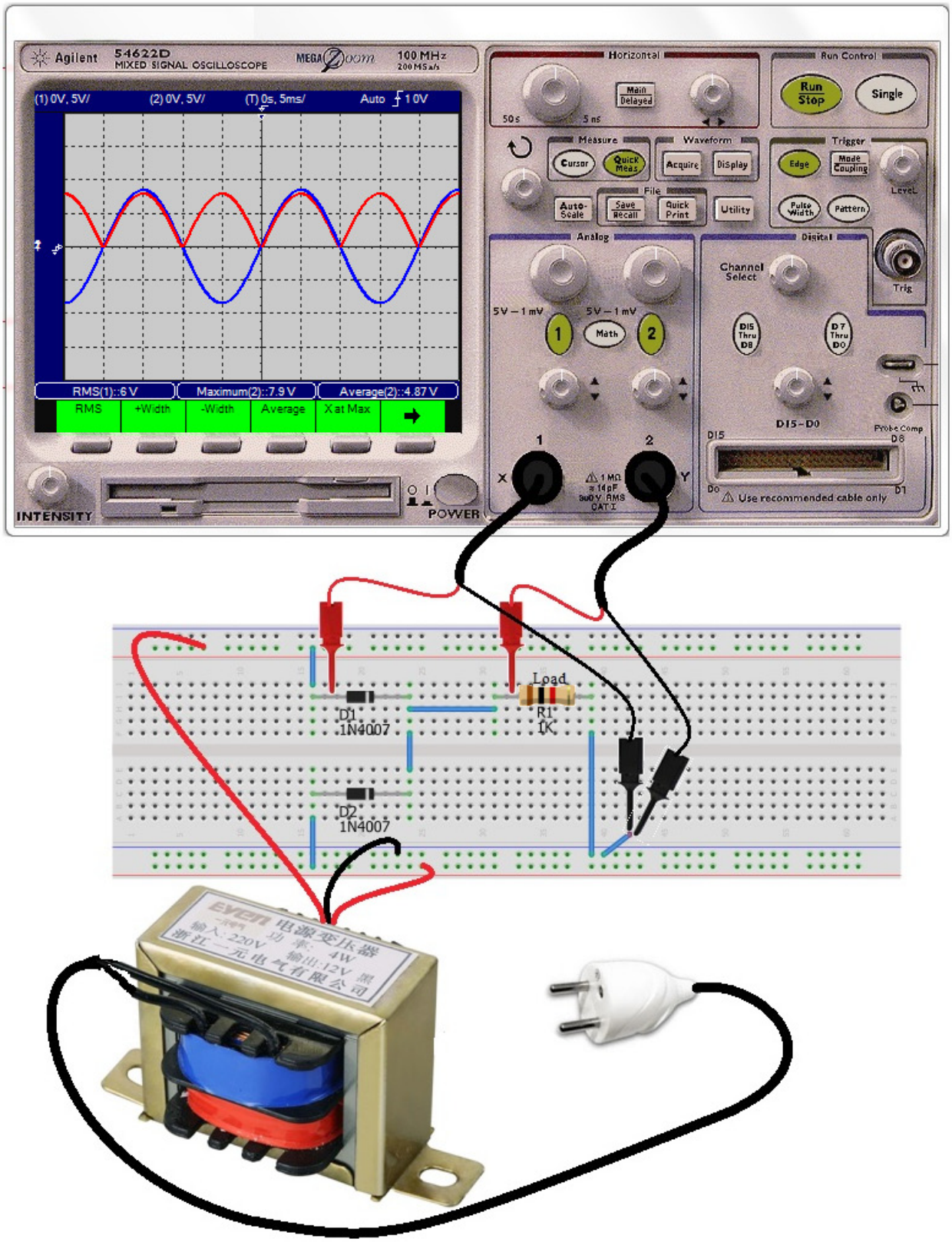


Figure 6-37: Two diodes full wave rectifier using centre tapped transformer, circuit connection

• **Two Diodes Full Wave Rectifier Advantages and Disadvantages**

Advantages	Disadvantages
• Great mean output voltage with respect to the half wave of the same input amplitude	• Inefficiently use of the transformer by make use of a half of the secondary winding of the transformer voltage
• Easier to provide smoothing as a result of ripple frequency	• The twice frequency hum on an audio circuit may be more audible
• Easy circuit design since it uses only two diodes	• Increased heating losses as a result of the way in which the two diodes full wave rectifier circuit operates, each half of the transformer is used for half of the time. This means that the current through each winding is twice what it would be if a true half wave rectifier such as a bridge rectifier were used.
	• To create a full wave rectifier using the two diodes full wave rectifier system would require a transformer times the size of the one needed for the bridge rectifier. This would cost more as well as being heavier and more bulky.
	• Requires power diodes capable to handle the peak inverse voltage.
	• The center tap must be exactly at the middle point otherwise the load is supplied by unequaly voltages. This make a transformer expensive and complex.

Table 6-3: Advantages and disadvantages of two diodes full wave rectifier

6. 4. Smoothing capacitor choice preference

The choice of the capacitor value needs to fulfill a number of requirements. In the first case the value must be chosen so that its time constant is very much longer than the time interval between the successive peaks of the rectified waveform.

$$R_{load} * C >> 1/F$$

Where:

R_{load}: The overall resistance of the load for the supply in Ohm,

C: The value of capacitor in Farads,

F: The ripple frequency - this will be twice the line frequency for the case of full wave rectifier.

The raw DC supplied by a rectifier on its own would consist of a series of half sine waves with the voltage varying between zero and Peak value ($\sqrt{2} * V_{rms}$ by ignoring any diode and other losses). A supply of this nature would not be of any use for powering circuits because any analogue circuits

would have the huge level of ripple superimposed on the output, and any digital circuits would not function because the power would be removed every half cycle.

Ripple Voltage

As there will always be some ripple on the output of a rectifier using a smoothing capacitor circuit, it is necessary to be able to estimate the approximate value. Over-specifying a capacitor too much will add extra cost, size and weight under specifying it will lead to poor performance.

Half wave ripple voltage: $V_{ripple} = I_{load}/(f\,C)$

Full wave ripple voltage: $V_{ripple} = I_{load}/(2f\,C)$

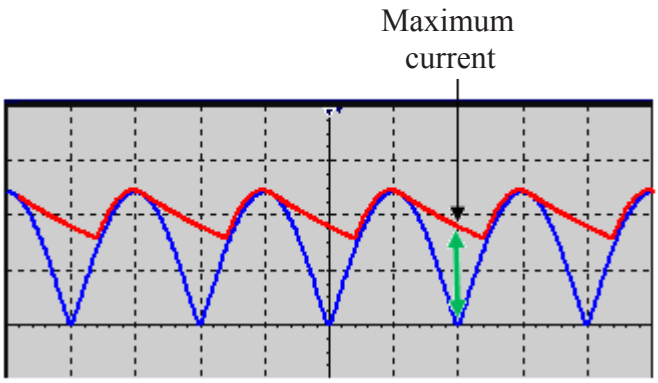
These equations provide more sufficient accuracy. Although the capacitor discharge for a purely resistive load is exponential, the inaccuracy introduced by the linear approximation is very small for low values of ripple. It is also worth remembering that once used, the input to a voltage regulator is not a purely resistive load but a constant current load. Finally, the tolerances of electrolytic capacitors used for rectifier smoothing circuits are large up to ±20% at the very best and this will mask any inaccuracies introduced by the assumptions in the equations.

Ripple Current

For applications where large levels of current may flow, as in the case of a rectifier smoothing capacitor, a third parameter which is its maximum ripple current becomes an important factor. The ripple current is not just equal to the supply current. There are two circumstances:

- **Capacitor Discharge Current**

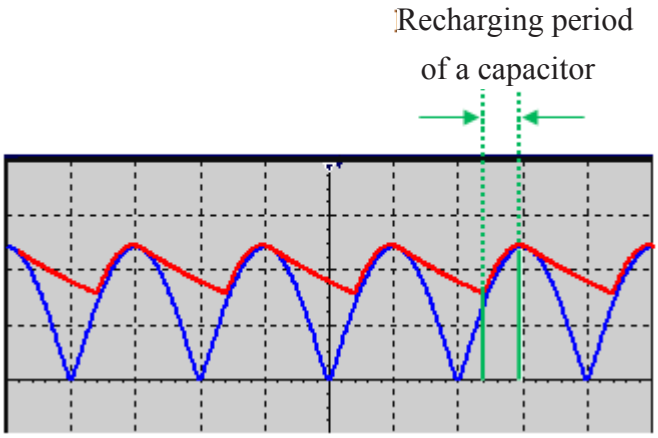
On the discharge cycle, the maximum current supplied by the capacitor occurs as the output from the rectifier circuit falls to zero. At this point all the current from the circuit is supplied by the capacitor. This is equal to the full current of the circuit.



- **Capacitor Charging Current**

On the charge cycle of the smoothing capacitor, the capacitor needs to replace all the lost charge, but it can only achieve this when the voltage from the rectifier exceeds that from the smoothing capacitor.

This only occurs over a short period of the cycle. Consequently the current during this period is much higher. The large the capacitor, the better it reduces the ripple and the shorter the charge period.



In view of the large currents involved, care must be taken to ensure that he ripple current does not exceed the rated values for the capacitor.

6. 5. Rectifier diodes

Rectifier diodes are used in power supplies to convert alternating current (AC) to direct current (DC), a process called rectification. They are also used elsewhere in circuits where a large current must pass through the diode. There are many different types of rectifier diode that can be used - each one with its own properties, advantages and disadvantages.

Diode	Maximum Current	Maximum ReverseVoltage
1N4001	1A	50V
1N4002	1A	100V
1N4007	1A	1000V
1N5401	3A	100V
1N5408	3A	1000V

Table 6-4: Diodes used in rectifiers and their basic characteristics

All these rectifier diodes are made from silicon and therefore have a forward voltage drop of 0.7V. The table shows maximum current and maximum reverse voltage for some popular rectifier diodes. The 1N4001 is suitable for most low voltage circuits with a current of less than 1A.

For power rectification applications, power diodes of Schottky diodes are normally used. For signal rectification small point contact diodes, signal diodes, or Schottky diodes may be used. The Schottky diode has the advantage that it only requires a forward voltage of around 0.2 - 0.3volts for forward conduction. This is particularly useful when detecting small radio signals, and when used as a power rectifier the power losses are reduced. However the reverse leakage characteristics are not as good as normal silicon diodes.

6. 6. Rectifier diode requirements

When designing a rectifier circuit, it is compulsory to make sure that the diode is capable of providing the required performance. While there are many parameters that define individual diodes, and these may need to be taken into account for a given design, some of the major parameters are detailed below:

- **Forward current:**

It is obligatory that the diode is able to handle the levels of average current and maximum current flowing through it in a rectifier circuit. The current will hit the highest point as a result of the capacitor smoothing circuit. As the current only flows as the capacitor charges up, the current is in short bursts which are much higher than the average current.

- **Peak inverse voltage:**

The diode must be able to reliably withstand the peak reverse or inverse voltages that appear across it. The peak voltages are not just the output voltage, but higher. The peak inverse voltage rating of the diode should be at least $2 \times \sqrt{2}$ times the RMS voltage of the input. This is because the output is normally smoothed by a capacitor, and this will take a value that is the peak of the input waveform. This will be $\sqrt{2}$ times the RMS voltage. With this voltage on the output, the input waveform on the "blocked" half of the cycle will fall and reach a peak value at the bottom of the crest of $\sqrt{2}$ times the RMS value. The maximum reverse value seen across the rectifier diode is the sum of these two voltages.

There should also be a significant margin, especially when used in a mains or line power supply. This is because voltage spikes can appear on the line.

Application of Rectifiers

- The primary application of rectifiers is to derive usable DC power from an AC supply. almost all electronic devices require a DC supply but mains power is AC so rectifiers find uses inside the power supplies of virtually all electronic equipments.
- Converting DC voltage from one level to another is much more complicated. One method of such DC to DC conversion is to first convert to AC (using a device called an inverter), then use a transformer to change the voltage, and finally rectify it back to DC.
- Rectifiers also find a use in detection of amplitude modulated radio signals. The signal may or not be amplified before detection but if unamplified a very low voltage drop diode must be used. In this case the capacitor and load resistance must be carefully matched. Too low a capacitance will result in the high frequency carrier passing to the output and too high will result in the capacitor just charging and staying charged.
- Rectifiers are also used to supply polarized voltage for welding. In such circuits control of the output current is required and this is sometimes achieved by replacing some of the diodes in bridge rectifier with thyristors, whose voltage output can be regulated by means of phase fired controllers.
- Rectifiers have many uses, but are often found serving as components of DC power supplies and high-voltage direct current power transmission systems. Rectification may serve in roles other than to generate direct current for use as a source of power. In general, recti-

fiers replace batteries and are found in radio, television, phone chargers, computer equipments and other electronics instruments that require DV voltage.

Hands on tip

The diode forward *V-I* Characteristic curve can be plotted on the oscilloscope using the circuit shown below. Channel 1 senses the voltage across the diode and channel 2 senses a signal that is proportional to the current. The scope must be in the X-Y mode. The signal generator provides a 5Vpp sawtooth or triangular waveform at 50Hz, and its ground must not be the same as the scope ground. Channel 2 must be inverted for the displayed curve to be propery oriented.

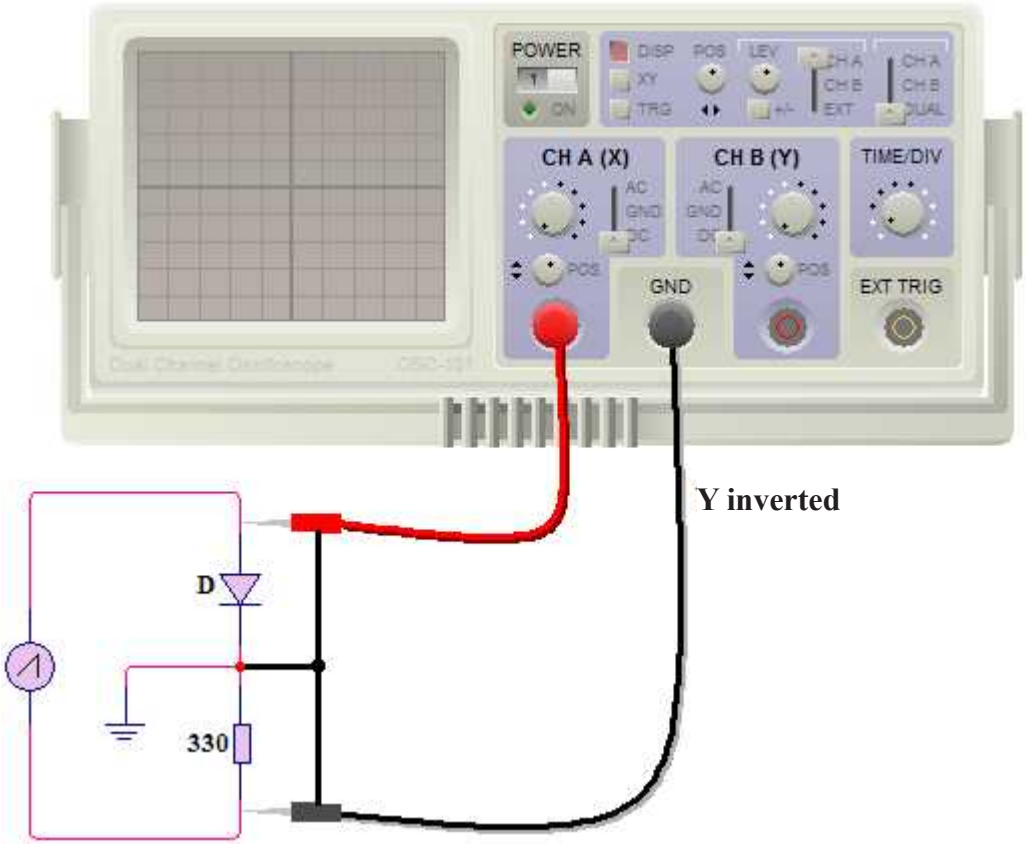


Figure 6-38: Circuit used to plot the diode forward *V-I* Characteristic curve on the oscilloscope

Chapter seven

Regulated DC Power Supply

Objectives

When you have studied this chapter, you should

- Have an understanding of working principle of Zener diode
- Be capable to design a supply with a constant DC voltage
- Be able to describe different 3-terminal ICs voltage regulators
- Be able to design dual polarity DC supply

Futher reading
Study aids for this chapter are available at the companion website
• http://www.circuitstoday.com/regulated-power-supply
• http://electrical4u.com/regulated-power-supply

7. 1. Voltage stabilization principle

A voltage from a rectifier varies with the load. Even if the smoothing capacitor can improve the wave form of a rectifier but as the resistance of connected load gets low, the amount of ripples increases since the time of discharging of a capacitor (RC) decreases. The way to overcome this behavior is achieved by using a voltage stabilizer device such as Zener diode which provides a constant voltage over a wide range of power supply voltages. Presume we are requested to build a circuit which cannot tolerate variations in power supply voltage, but need to be powered by a chemical battery, whose voltage changes over its lifetime. We have to form a circuit as shown in figure 7-1 and connect the circuit requiring steady voltage across the diode, where it would receive an unchanging 0.7 volts.

Even though we connect a diode and resistor in series with a DC voltage source so that the diode is forward biased, the voltage drop across the diode will remain fairly constant over a wide range of power supply voltages as in figure 7-2.

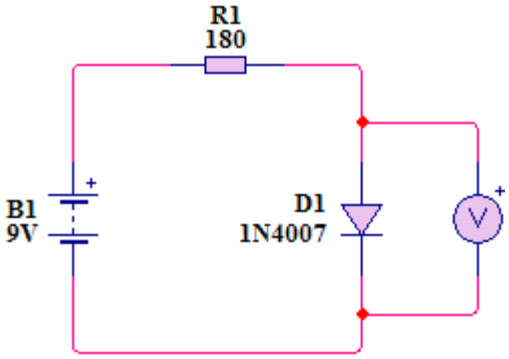


Figure 7-1: One ordinary diode used as voltage stabilizer circuit

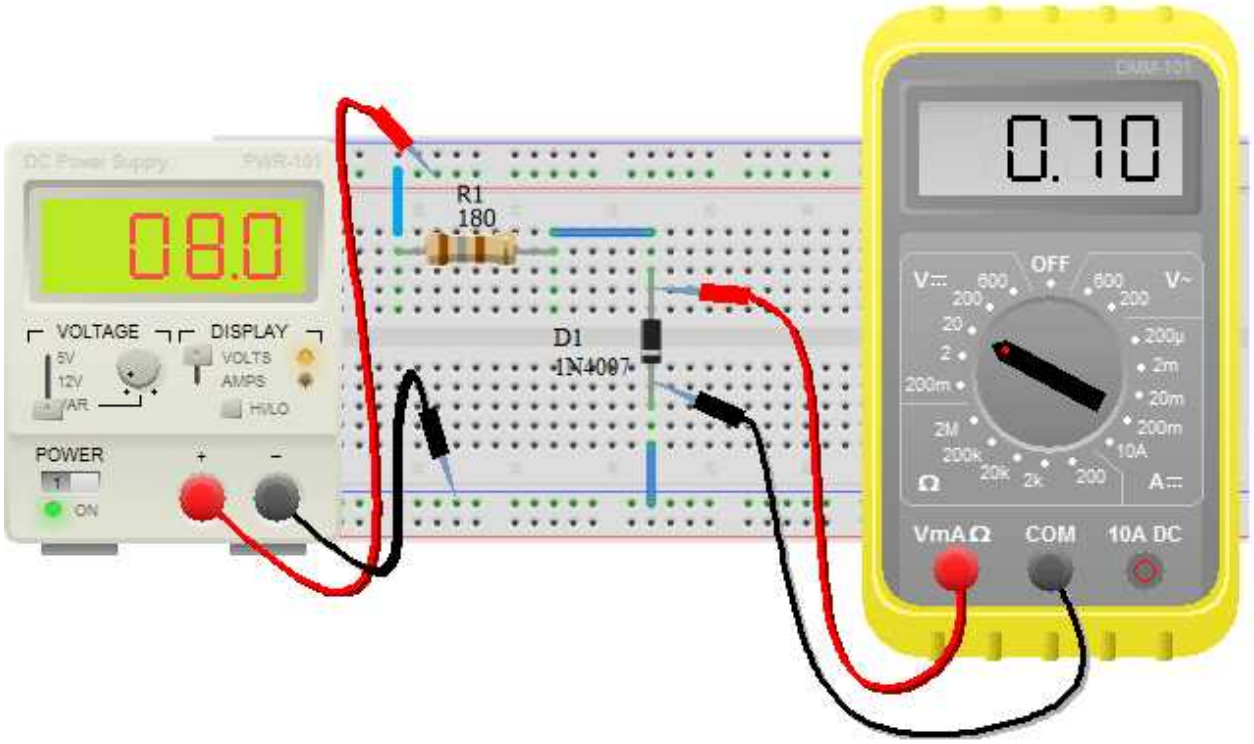


Figure 7-2: One ordinary diode used as voltage stabilizer circuit connection

The circuit figure 7-2 will without doubt work, but most practical circuits of the same kind require a power supply voltage in excess of diode voltage drop (0.7V) to properly function. One way we could increase our voltage regulation point would be to connect multiple diodes in series, so that their individual forward voltage drops of 0.7 volts each would add to create a larger total. For instance, if we had five diodes in series, the regulated voltage would be five times 0.7V (5*0.7V) that is 3.5V. The equivalent circuit is shown in figure 7-3.

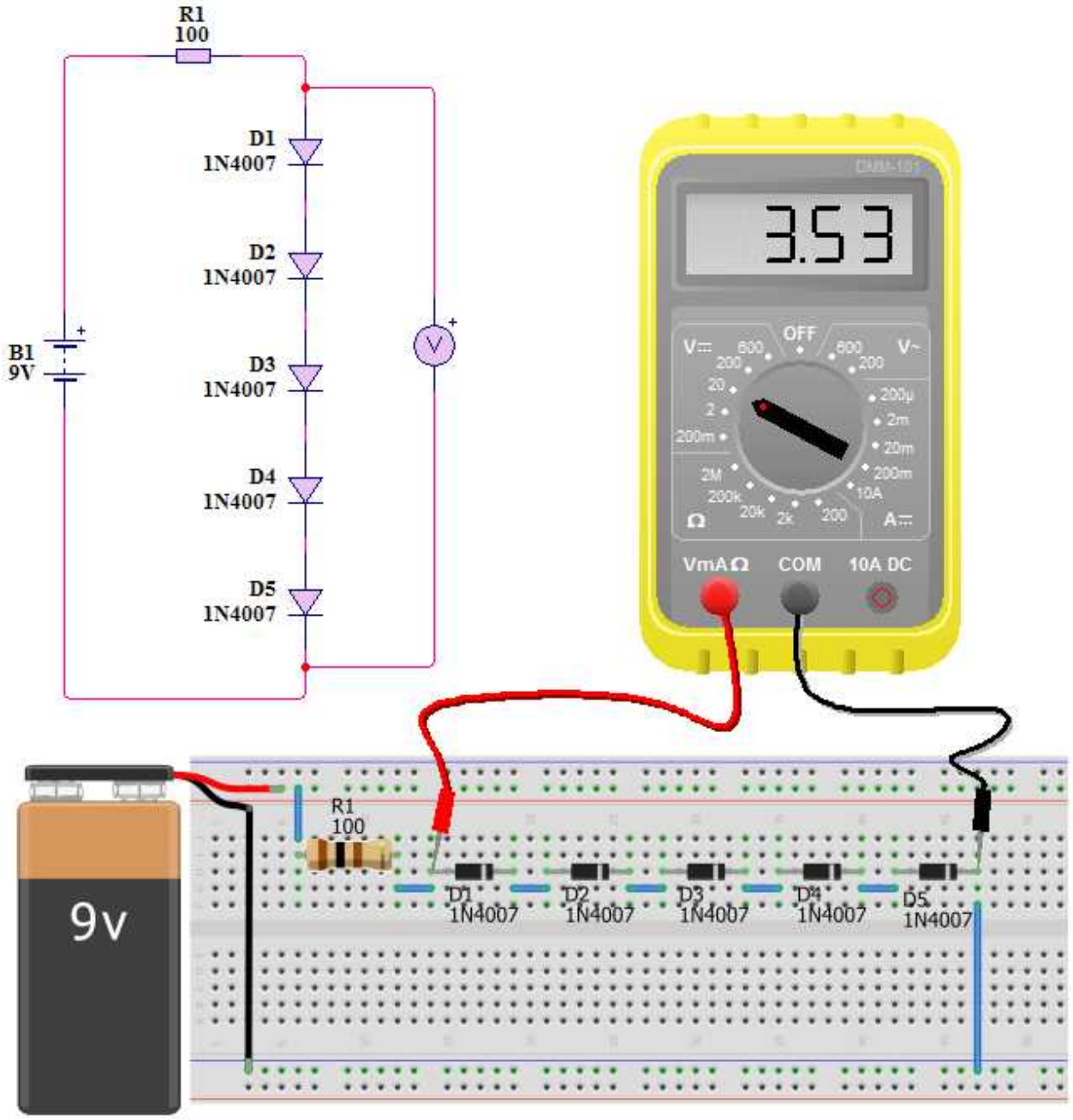


Figure 7-3: Five ordinary diodes used as voltage stabilizer

So long as the battery voltage never sagged below 3.5 volts, there will always be about 3.5 volts dropped across the five diode load up. Whenever larger stabilized voltages are required, we can either use more diodes in series, which takes a big size, or make another arrangement. From the circuit configuration above, in figure 7-3, it is shown that diode forward voltage is fairly constant under a wide range of conditions. But if we reverse the polarity of the diode in our single-diode stabilization circuit and increase the power supply voltage to the point where the diode "broke down" (could no longer withstand the reverse bias voltage impressed across it), the diode would similarly stabilize the voltage at that breakdown point, not allowing it to increase further.

Unfortunately, when normal rectifying diodes "break down," they usually do so destructively. However, it is possible to build a special type of diode that can handle breakdown without failing completely. This type of diode is called a Zener diode.

7. 2. Zener diode

Zener diode is a general purpose diode, which behaves like a normal diode when forward biased, But when it is reverse biased above a certain voltage known as Zener breakdown voltage or zener voltage or avalanche point or zener knee voltage the voltage remains constant for a wide range of current.

DC power supply consists only of a transformer, full-wave rectifier, and filter capacitor are used with success in many practical applications. However, this basic circuit has several important disadvantages:

1. The capacitors required to reduce the ripple voltage to a small magnitude are physically large and expensive;
2. Even with minimal ripple, the output voltage can vary considerably due to AC line voltage fluctuations; and
3. Changes in load current can lead to changes in output voltage due to the voltage drops across the internal resistances of the rectifier diodes and transformer windings.

These deficiencies can be addressed through the use of a voltage regulator circuit, which maintains the output voltage of the power supply close to a predetermined level. Zener diodes, which exhibit very stable voltages across themselves when operated in their reverse breakdown regions, serve as simple yet effective voltage regulators in a wide range of applications.

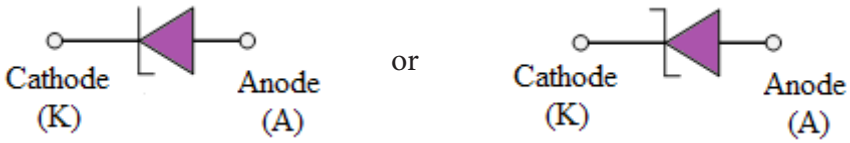


Figure 7-4: Symbols of Zener diode

Zener Diode I-V Characteristics

It is with this characteristic that makes the Zener diode useful as a voltage stabilizer. If a load is connected in parallel with the diode, and if the diode's operating point is maintained in the reverse breakdown region, then the voltage across the diode, and therefore the voltage across the load, will remain very close to the Zener voltage.

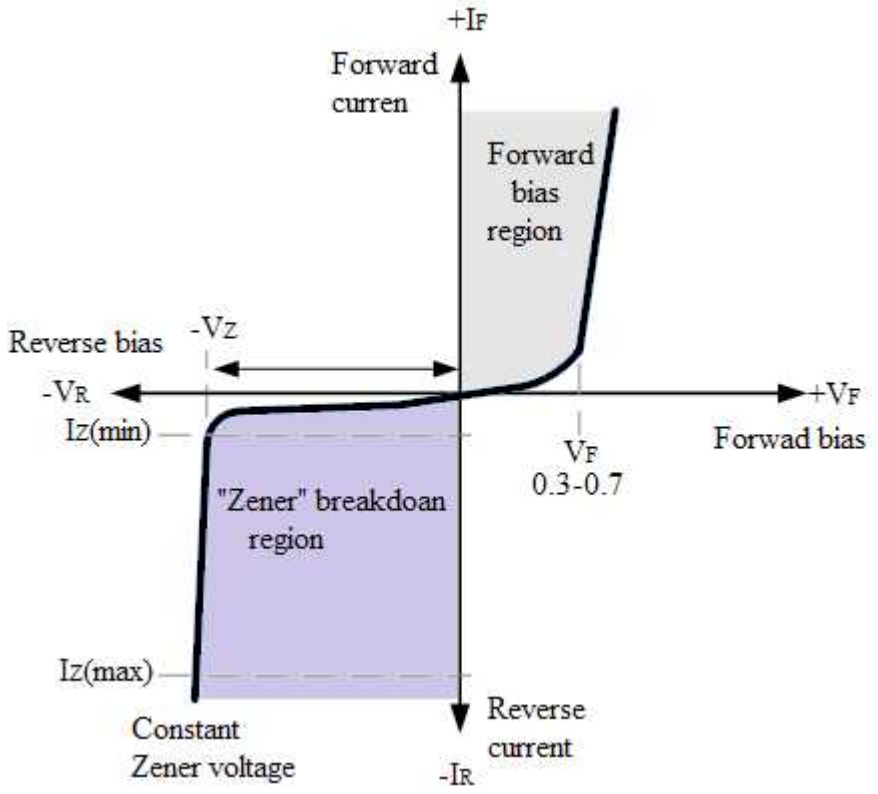


Figure 7-5: Zener Diode I-V Characteristics

Where:

V_F: Forward bias voltage in Volts,

V_R: Reverse bias voltage in Volts,

V_Z: Zener breakdown voltage,

I_F: Current passing through a Zener diode when forward biased,

I_R: Current passing through a Zener diode when reverse biased without reaching breakdown,

I_Z: current through a Zener diode at its breakdown voltage.

For the proper designing of the Zener diode stabilizer you have to know:

- Unregulated Input Voltage Range
- Required Output Voltage
- Max Load Current Required

The Zener diode requires a series resistor Rs that limits the current that can damage the device. The value of Rs must be small enough to keep the Zener diode in reverse breakdown region. The minimum current required for a Zener Diode to keep it in reverse breakdown region will be given in its datasheet. For example, a 5.6 V, 0.5 W Zener diode has a recommended reverse current of 5 mA. If the reverse current is less than this value, the output voltage will be unregulated.

The value of Rs must be large enough so that the current through the zener diode should not destroy it. That is the maximum power dissipation (P_{max}) should be less than *Iz*Vz.

Thus we should find $R_{s(min)}$ and $R_{s(max)}$. To find the value of $R_{s(min)}$ we should consider the extreme condition that is V_{in} minimum and load current is maximum.

$$I_s = I_{z(min)} + I_{L(max)}$$
$$I_{z(min)} = \text{see Datasheet}$$
$$V_s = V_{in(min)} - V_z$$
$$R_{s(min)} = V_s / I_s$$

To find the value of $R_{s(max)}$ we should consider the extreme condition that is V_{in} maximum and load current is minimum (ie, no load connected).

$$I_s = I_{z(max)} + I_{L(min)}$$
$$I_{z(max)} = P_{max} / V_z$$
$$V_s = V_{in(max)} - V_z$$
$$R_{s(max)} = V_s / I_s$$

Stabled Multiple Output Supply

Industrial applications generally require a number of outputs to supply Analog and digital low voltage circuitry. In a world where glamorous portable devices such as smart phones and tablet computers dominate the headlines, it is easy to forget that most consumer electronic products draw power from the mains supply. And yet, these products use the same sensitive silicon requiring stable, low-voltage power. Despite the fact that mains outlets around the world supply AC voltages from 90 to 264 V running at frequencies from 47 to 63 Hz, almost all office and home equipment cannot be plugged straight into a wall socket without some kind of power conversion. Motor Control applications often require several separately isolated outputs to supply half-bridge drivers and control circuitry. Typical consumer applications of these multiple output converters include Television and related products such as set- top decoders and Video cassette recorders (VCRs). This article explains the basics of power regulation in mains-powered devices, from the line transformer that converts the high mains voltage to an isolated low voltage, through AC line rectification methods to convert the AC voltage to DC, and then to the DC/DC converter options that supply the stable low-voltage outputs required by the electronics.

Experiment 7-1: Zener Diodes Series Connection (multi-output voltage)

Some sub-circuits on motherboard require different voltage form a single DC supply. By connecting Zener diodes in series, these share the same DC supply voltage and the individual Zener voltage sum up.

Build a power supply, based on Zener diodes and ordinary diodes, with four outputs where you can connect a load requiring 10V, 10.7V, 14V and 19.1V from 24V DC supply.

Part lit

No	Items	Specifications	Quantity
1	Voltmeter	Digital Multimeter	4
2	Zener diode	Zener diode BZV55C10V0	1
3	Zener diode	Zener diode BZV55-B3V3	1
4	Resistor	150 Ω	1
5	Small signal diode	1N4148	1
6	Zener diode	Zener diode BZV55-B5V1	1
7	Connecting Wire	22-gauge (0.33mm^2)wire	30cm
8	Breadboard	Prototyping board	1
9	24VDC supply	24V DC power supply	1

From schematic circuit figure 7-6, each voltmeter reading is captured from the terminal where a requested voltage to supply a specific sub-circuit is taken from. No worry from voltmeter reading deviation since Zener diodes are manufactured with zener voltages ranging anywhere from a few volts to hundreds of volts.

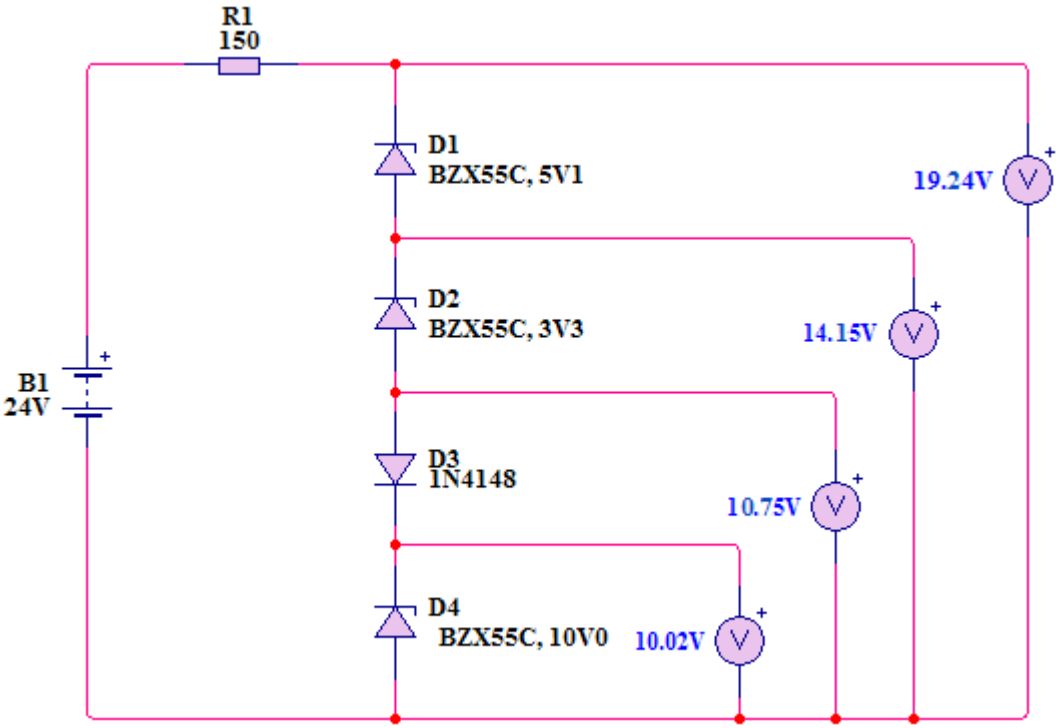


Figure 7-6: Zener Diodes Series Connection (multi-output voltage) circuit

This zener voltage changes slightly with temperature, and like common carbon-composition resistor values, may be anywhere from 5 percent to 10 percent in error from the manufacturer's specifications. However, this stability and accuracy is generally good enough for the zener diode to be used as a voltage regulator device in common power supply circuits.

Working Principle of the Circuit

The input B_1 is from regulated dc voltage and must be high enough (greater than 22V) to maintain the required maximum voltage to be delivered. R_1 serves as the input current limiter, and D_1 to D_4 as voltage regulators and each sets the desired output voltage on its terminal.

D_4 outputs 10V on its terminals taken from ground and to its cathode.

D_3 outputs 10.7V (10V of the D_4 + 0.7V of the diode drop when forward biased) from ground to its anode.

D_2 outputs 14V (10V of D_4 + 0.7V of D3 + 3.3V of BZX55C,3V3 zener) and this 14V is taken from ground to the cathode of D_2.

D_1 outputs 19.1V (10V of D_4 + 0.7V of D_3 + 3.3V of D_2 + 5.1V of BZX55C,5V1 zener) and this 19.1V is taken from ground to cathode of D_1.

In practice these outputs voltage can deviate to a tolerable amount as indicated on voltmeters.

The values of the individual Zener diodes can be chosen to suit the application while the silicon diode will always drop about 0.6 to 0.7V in the forward bias condition. The supply voltage, V_{in} must of course be higher than the largest output reference voltage and in our example above this is 19.1V.

Hands on tip

An electronic power supply provides both output voltage and current. You should make sure the voltage range is sufficient for your applications. Also, you must have sufficient current capacity to assure proper circuit operation. The current capacity is the maximum current that a power supply can provide to a load at a given voltage.

Safety point

To avoid electrical shock, never touch circuit while it is connected to a voltage source. If you need to handle a circuit, remove a component, or change a component, first make sure the voltage source is disconnected.

Series Resistor Requirements

The value of series resistor must satisfy two conditions:

1. The series resistor (RS) must be small enough that the current through the Zener diode keeps it in reverse breakdown. The value of this current is given in the data sheet for chosen Zener type. For example, the common BZX79C5V6 device, a 5.6 V 0.5 W Zener diode, has a recommended reverse current of 5 mA. Whenever unsatisfactory current exists through Zener diode, then output voltage will be unregulated, and less than the nominal breakdown voltage. When calculating the series resistor value, allowance must be made for any current through the external load. This means that with a large series resistor most of power will be wasted through it and no current across the zener diode and so no regulation as shown in figure 7-8.

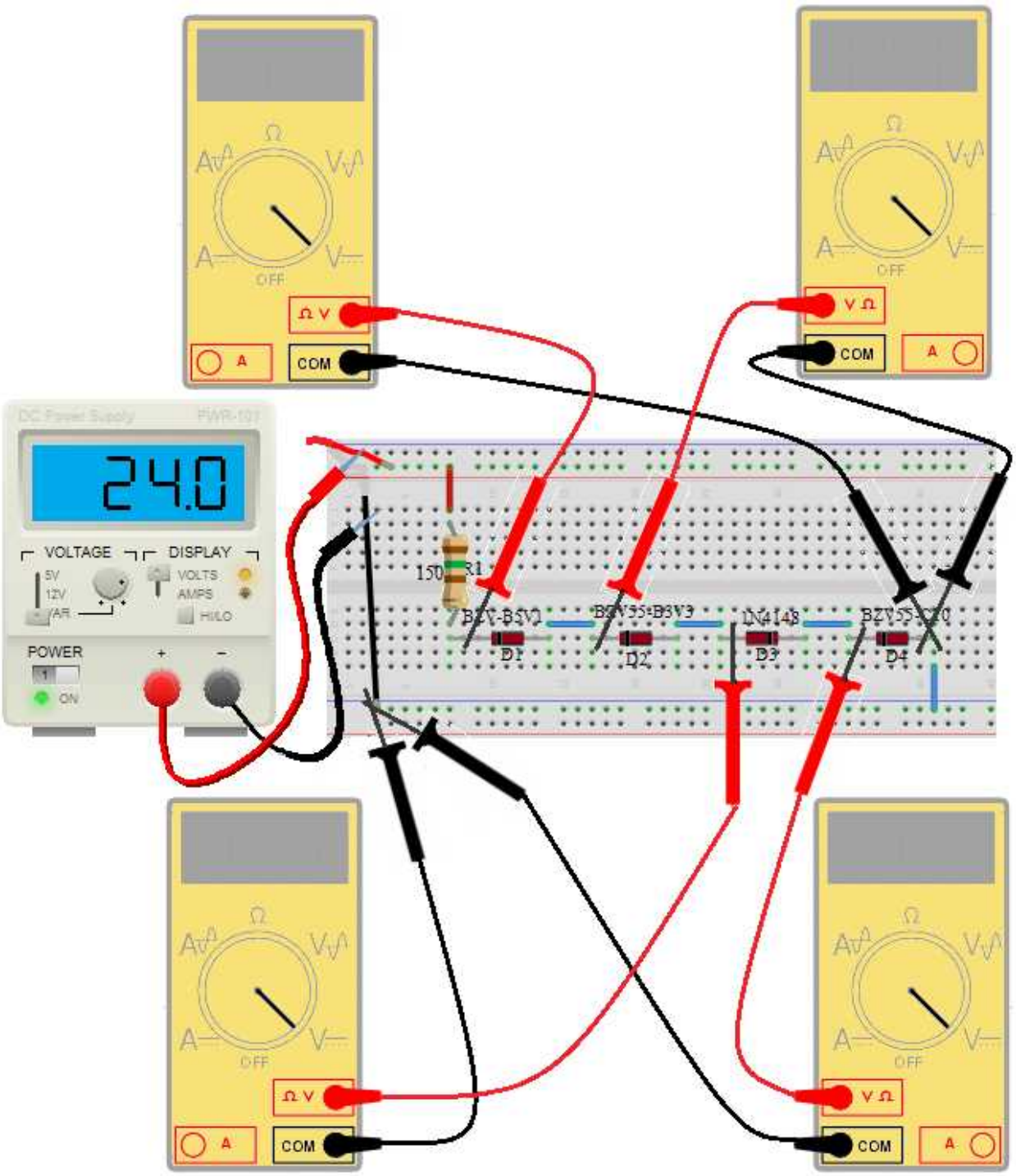


Figure 7-7: Zener Diodes Series Connection (multi-output voltage), real world circuit connection

2. The low series resistor to a specific value allows a great current to pass through a Zener diode and this can destroy the device. If the current through the Zener diode is I_Z, V_Z its breakdown voltage and P_{MAX} its maximum power dissipation, then I_Z*V_Z<P_{MAX}.

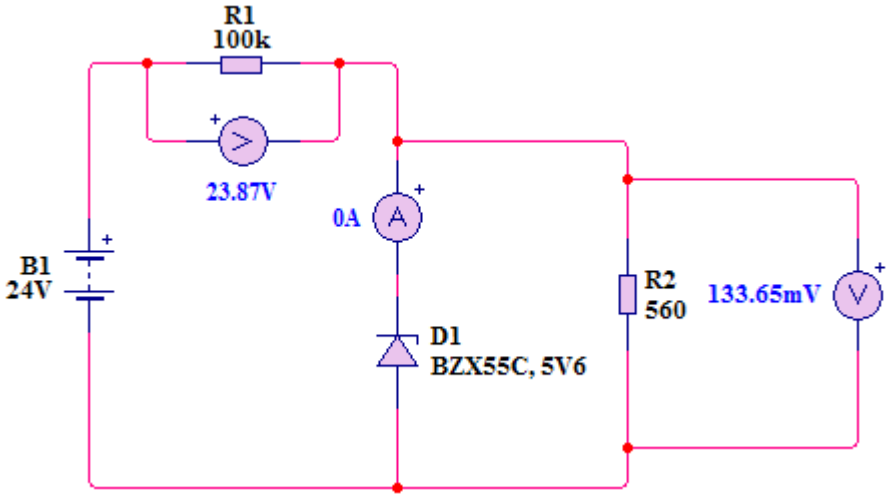


Figure 7-8: Zener voltage stabilizer circuit with high series resistor

To have a regulated output voltage requires to use a supply battery, here named B_1, with hundreds volts which cannot happen.

A load may be placed across the diode in the circuit, and as long as the Zener stays in reverse breakdown, the diode will provide a stable voltage source to the load. Zener diodes in such configuration are often used as stable references for more advanced voltage regulator circuits.

Shunt regulators require that the ballast resistor to be small enough to avoid excessive voltage drop during worst-case operation (low input voltage concurrent with high load current) tends to leave a lot of current flowing in the diode much of the time, making for a fairly wasteful regulator with high quiescent power dissipation, only suitable for smaller loads.

Circuit Guidelines

The Zener diode is a very useful circuit component in DC voltage regulators. However, like any other electronic components, there are a few hints and tips which enable the best to be made of the Zener diode. A number are listed below.

- **Choose correct voltage for best stability**

In applications where stability with temperature changes is required, the Zener voltage reference diode should be chosen to have a voltage of around 5.5 volts. The nearest preferred value is 5.6 volts although 5.1 volts is another popular value in view of its proximity to 5 volts required for some logic families. Where different levels of voltage are required, the 5.6 volt Zener can be used and the surrounding electronic can be used to transfer this to the required output value.

- **Buffer the Zener diode circuit with an emitter or source follower**

To keep the voltage from the Zener diode as stable as possible, the current flowing through the Zener diode must be kept constant. Any variations in current drawn by the load must be minimized as these will change the current through the Zener diode and cause slight voltage variations. The changes caused by the load can be minimized by using an emitter follower stage to reduce the current taken from the Zener diode circuit and hence the variations it sees. This also has the advantage that smaller Zener diodes may be used.

- **Drive with constant current source for best stability**

Another way of improving the Zener stability is to use a good constant current source. A simple resistor is adequate for many applications, but a more effective current source can provide some improvements as the current can be maintained almost regardless of any variations in supply rail.

- **Ensure sufficient current for reverse breakdown**

It is necessary to ensure that sufficient current is passed through the diode to ensure that it remains in reverse breakdown. For a typical 400mW device a current of around 5 mA must be maintained. For exact values of minimum current, the datasheet for the particular device and voltage should be consulted.

- **Ensure maximum limits of current are not exceeded for the Zener diode**

While it is necessary to ensure sufficient current is passed through the Zener diode, the maximum limits must not be exceeded. This can be a bit of a balancing act in some circuits as variations in load current will cause the Zener diode current to vary. Care should be taken not to exceed the maximum current or the maximum power dissipation (Zener voltage x Zener diode current). If this appears to be a problem, an emitter follower circuit can be used to buffer the Zener diode and increase the current capability.

When used to their best, Zener diodes can provide very high levels of performance. They often exceed the performance required, but in view of their ease of use and low cost, they provide a very effective option to use.

Zener diodes Codes Identification

Zener diodes can be distinguished from ordinary diodes by their code and breakdown voltage which are printed on them. There are a number of zener diode types but the most used begin with BZX... or BZY.... Their breakdown voltage is printed with V in place of a decimal point, so 5V1 means 5.1 V for example.

Zener diodes are rated by their breakdown voltage and maximum power:

- The minimum voltage available is 2.4V.
- Power ratings of 500mW and 1.3W are common.

A typical Zener diode for general electronic circuits is the 500mW, *BZX55* series or the larger 1.3W, *BZX85* series were the Zener voltage is given as, for example, *C6V2* for a 6.2 V diode giving a diode reference number of *BZX55C6V2*. The 500 mW series of Zener diodes are available from 2.4 up to about 100 volts and typically have the same sequence of values as used for the 5% (E24) resistor series with the individual voltage ratings. The most useful diodes are given in the table 7-1.

7. 2. 2. Zener Diode Standard Voltages

BZX55 Zener Diode Power Rating 500mW							
2.4V	2.7V	3.0V	3.3V	3.6V	3.9V	4.3V	4.7V
5.1V	5.6V	6.2V	6.8V	7.5V	8.2V	9.1V	10V
11V	12V	13V	15V	16V	18V	20V	22V
24V	27V	30V	33V	36V	39V	43V	47V
BZX85 Zener Diode Power Rating 1.3W							
3.3V	3.6V	3.9V	4.3V	4.7V	5.1V	5.6	6.2V
6.8V	7.5V	8.2V	9.1V	10V	11V	12V	13V
15V	16V	18V	20V	22V	24V	27V	30V
33V	36V	39V	43V	47V	51V	56V	62V

Table 7-1: Zener Diode Standard Voltages

Experiment 7-2: Zener regulator from half wave rectifier voltage source

Zener diodes act much the same as standard rectifying diodes when forward-biased and they have a forward voltage drop which follows the "diode equation" and is about 0.7 volts. In reverse bias configuration, they do not conduct until the applied voltage reaches or exceeds the so-called Zener voltage, at which point the diode is able to conduct substantial current, and will try to limit the voltage dropped across it to that Zener voltage point. So long as the power dissipated by this reverse current does not exceed the diode's thermal limits, the diode will not be harmed. As the current from half wave rectifier encompass an excess of variations, one way to maintain a constant output voltage is to bring into play the Zener diode as stabilizer. The list of materials is given below.

Part list

No	Items	Specifications	Quantity
1	9VAC supply	Function generator	1
2	Oscilloscope	Agilent oscilloscope 54622D	1
3	Resistor	560Ω, 1/2watt	1
4	Resistor	100 Ω, 1/2watt	1
5	Diode	1N4001	1
6	Diode	Zener diode BZV55-B5V1	1
7	Connecting Wire	22-gauge (0.33mm^2)wire	50cm
8	Breadboard	Prototyping board (RSR 03MB102)	1

The Zener diode orientation in the circuit is reverse-biased, and with intent so. If we had oriented the diode in the "normal" way, so as to be forward-biased, it would only drop 0.7 volts, just like a regular rectifying diode.

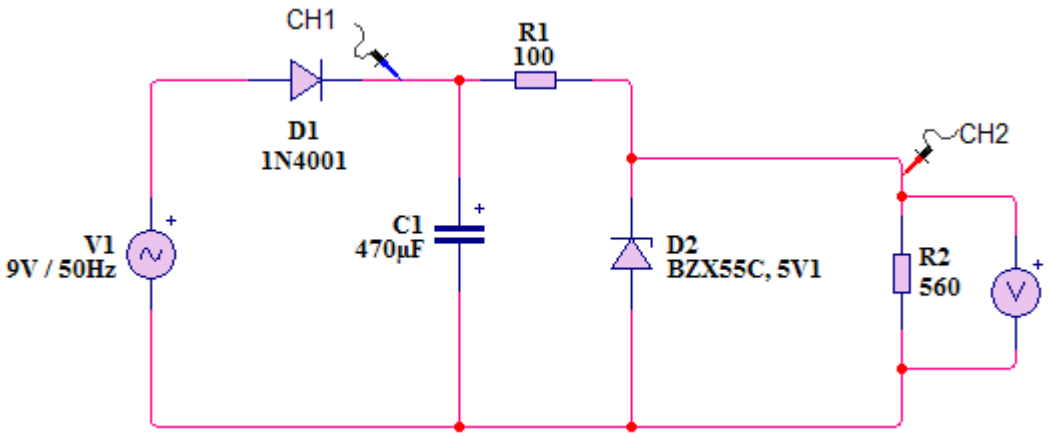


Figure 7-9: Zener regulator from half wave rectifier circuit

As we want to exploit this diode's reverse breakdown properties, we have made it to work in its reverse-bias mode. So long as the power supply voltage remains above the Zener voltage (5.1 volts, in this experiment), the voltage dropped across the Zener diode will remain at approximately 5.1 volts.

In the above circuit diagram, figure 7-9, a series resistor R_1 limits the current through the Zener diode D_2 by creating a voltage drop ($V_{in} - V_z$) across it.

Set function generator to output $9V_{rms}$/50Hz (you can also use 9V or 12V transformer). Set both channel one (CH1) and channel two (CH2) of oscilloscope to 5V volt/div and to 10mS time/div.

The channel one (CH1) of the oscilloscope displays no-stabilized voltage direct to the output of a rectifier while the channel two (CH2) displays stabilized voltage on the terminal on a load resistor. The load resistor must be connected in parallel to the Zener diode and thus will have the same voltage.

You can adjust vertical sensitivity and horizontal sensitivity to make the wave take up most of the screen without chopping any of its amplitude off and in the easy way reading and calculation. The output voltage is taken on R_2, just on the terminals of the load resistor or directy to the terminal on zener diode D_2. The oscilloscope should be AC coupled to read the input waveform but should be DC coupled to read the output waveform.

The oscilloscope display may have a natural coarseness, which can be reduced by selecting the Average function. Try to use as few samples as possible to avoid long delays while moving from one display to another.

Push the AUTOSCALE button to display both channels. Reposition so that the 0V is at the mid-line on the both channels and the waveforms appear to overlap.

At very high frequencies AUTOSCALE may not work because the filtered signal is too small. Use manual adjustments of the volts/division to reveal the signal. At least one full period of the waveform must be in view to for the oscilloscope measure functions to be accurate.

As seen from oscilloscope, the voltage on the terminal of load resistor is constant and fixed at 5.1V despite the change of the input voltage.

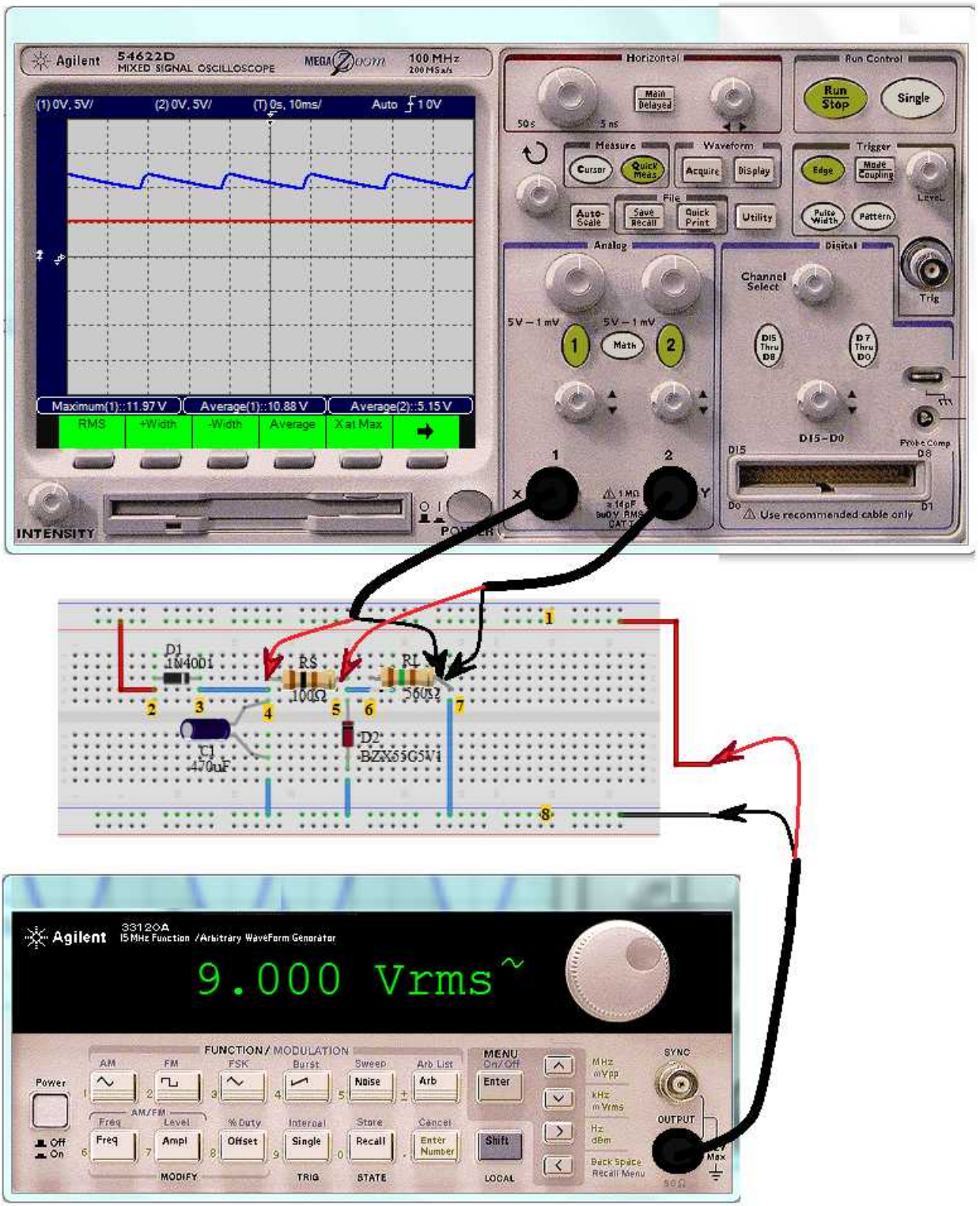


Figure 7-10: Zener regulator from half wave rectifier, circuit connection with oscilloscope for measuring

Instead of using oscilloscope, the resulting output voltage can be measured from voltmeter as shown in figure 7-11.

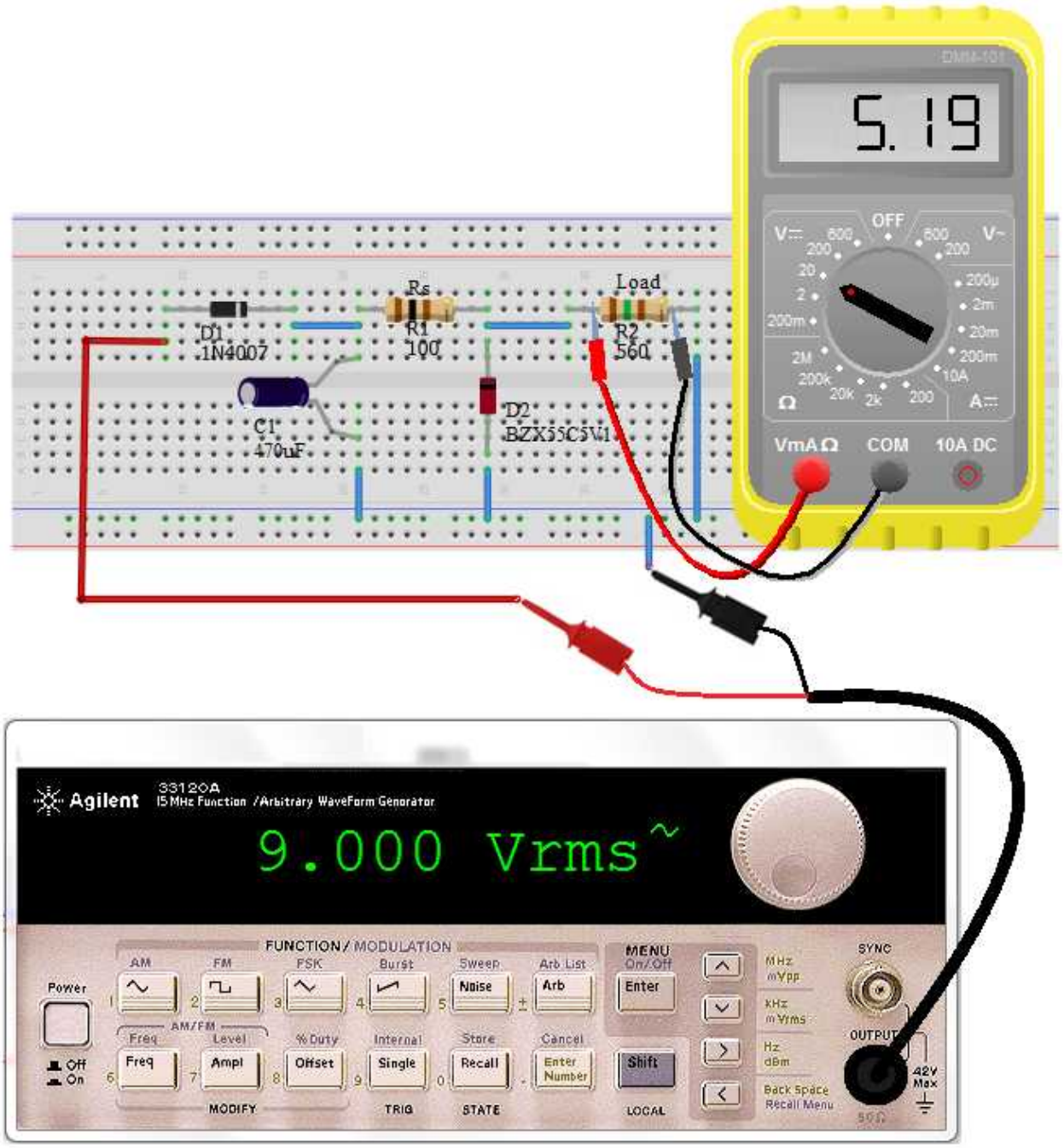


Figure 7-11: Zener regulator from half wave rectifier, circuit connection with voltmeter

Experiment 7-3: Zener diode stabilizer from full wave rectifier using BZV55-B6V2

Even if a full wave rectifier gives easy way for smoothing by using a small capacitor but as the load resistance decreases, the amount of voltage variation increases and this can have a negative effect on connected load. To overcome this voltage variation, a Zener diode stabilizer is inserted at output of a rectifier and provides a stable output voltage despite the change on input voltage.

Part list

No	Items	Specifications	Quantity
1	9VAC supply	Agilent function generator 33120A	1
2	Oscilloscope	Agilent oscilloscope 54622D	1
3	Resistor	820Ω	1
4	Resistor	100 Ω	1
5	Diode	1N4001	4
6	Zener diode	Zener diode BZV55-B6V2	1
7	Connecting Wire	22-gauge wire	40cm
8	Breadboard	Prototyping board (RSR 03MB102)	1

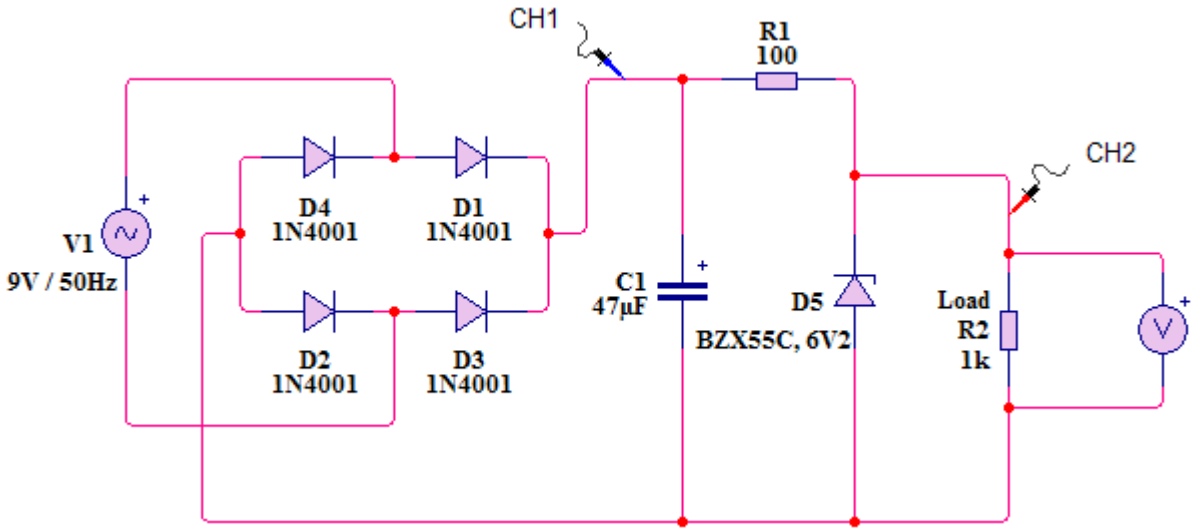


Figure 7-12: Zener diode stabilizer from full wave rectifier circuit

Use the function generator or a transformer to supply the sircuit with 9V/50Hz or 12V/50Hz. You can use any other varying AC source with acceptable minimum and maximum voltage depending on the series resistor and zener voltage.

Set both CH1 and CH2 of oscilloscope to 5V volt/div and to 5mS time/div. Push the AUTOSCALE button to display both channels. Reposition so that the 0V is at the midline on the both channels and the waveforms appear to overlap. The channel one (CH1) displays unregulated voltage directly to the output of rectifier while channel two of oscilloscope shows a regulated voltage from a zener regulator. Press on MEASSURE and measure maximum and minimum input voltage on CH1. Measure also the output average voltage just on load resistor at CH2.

As seen from oscilloscope, the voltage from output of rectifier varies between 7.64V to 12.01V, minimum and maximum voltage respectively.

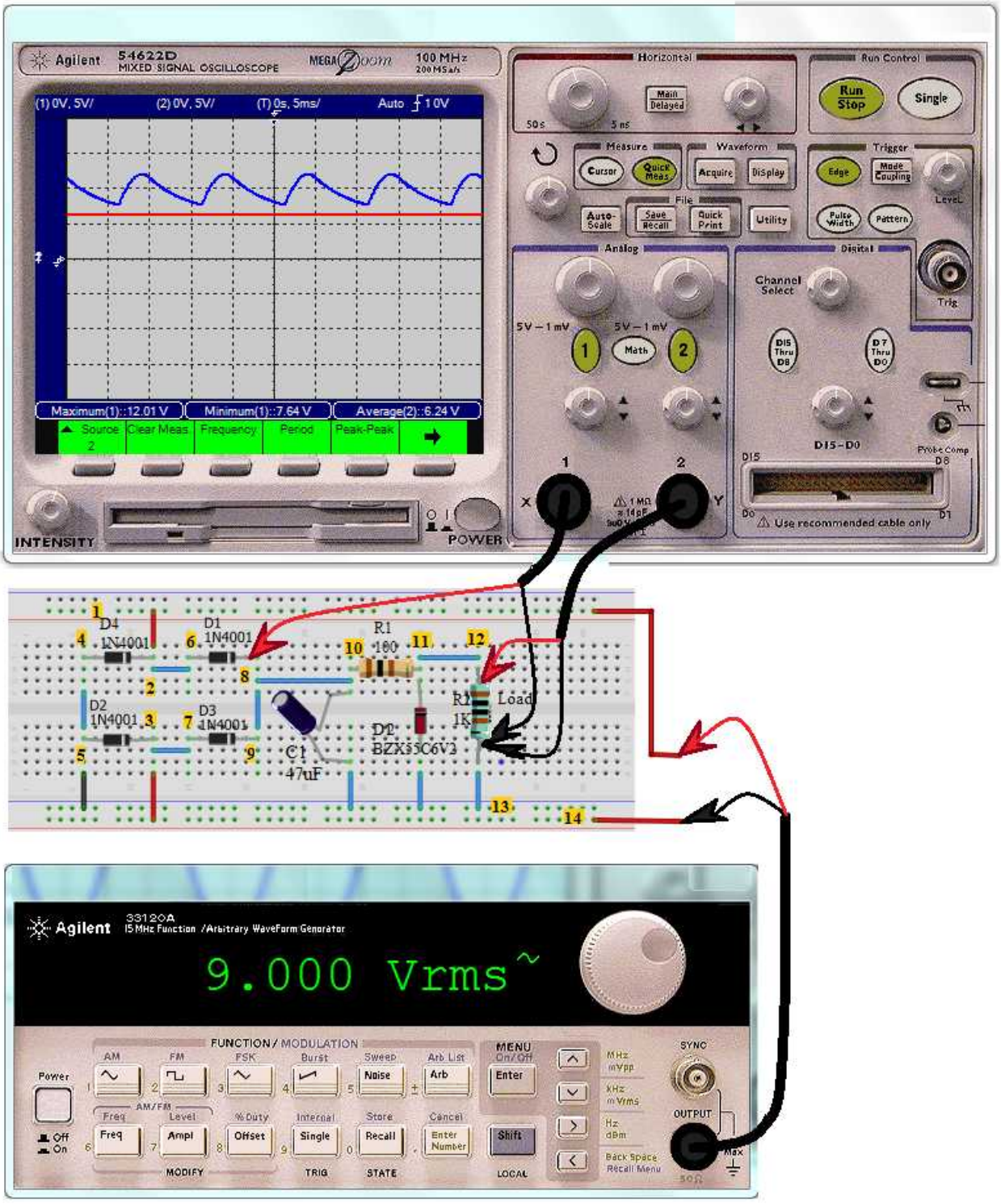


Figure 7-13: Zener diode stabilizer from full wave rectifier circuit, real world circuit connection with oscilloscope for measuring

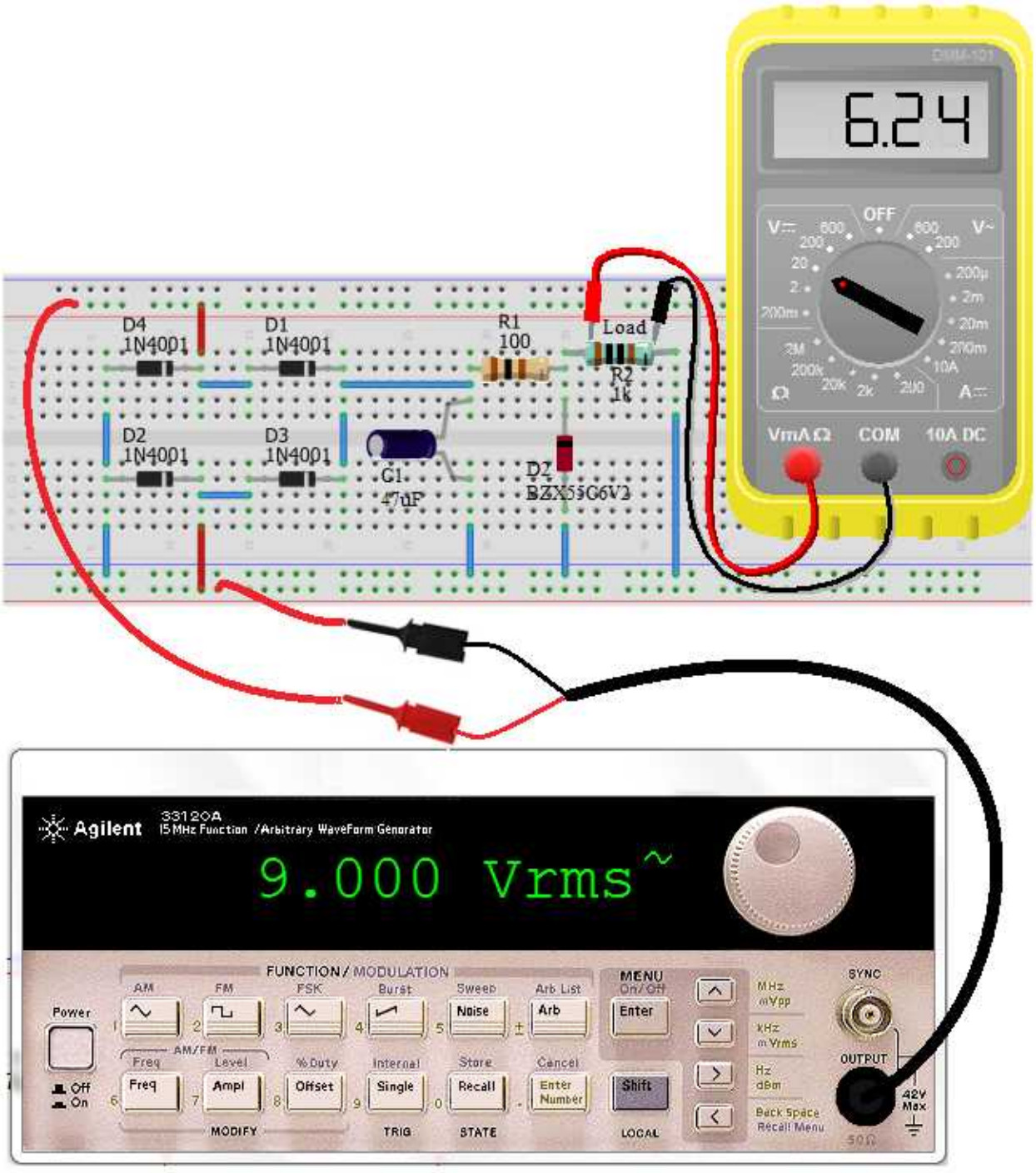


Figure 7-14: Zener regulator from full wave rectifier circuit, real world circuit connection with voltmeter reading

Zener diodes work by limiting voltage to some maximum level; they cannot make up for a lack of voltage. Any zener diode regulating circuit will function so long as the load's resistance is equal to or greater than some minimum value. If the load resistance is too low, it will draw too much current, dropping too much voltage across the series dropping resistor, leaving insufficient voltage across the zener diode to make it conduct. When the zener diode stops conducting current, it can

no longer regulate voltage, and the load voltage will fall below the regulation point as shown in figure 7-15.

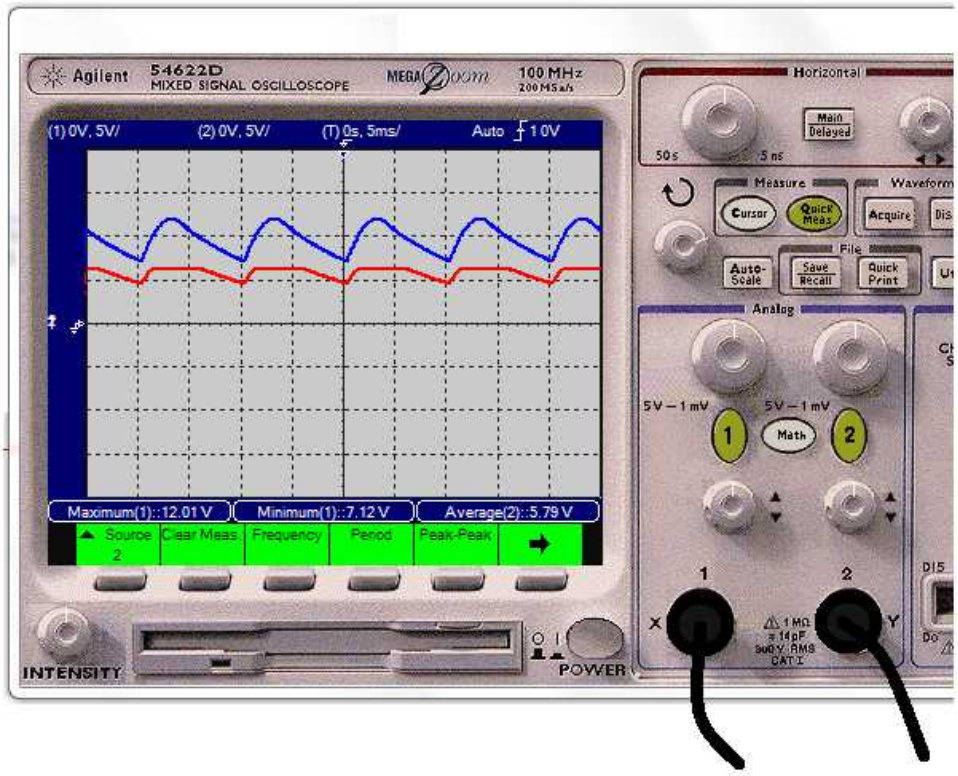


Figure 7-15: Zener diode stabilizer from full wave rectifier circuit with overload

These waveforms are results obtained by replacing 1KΩ load resistor with 68Ω. The design procedure for Zener stabilizer circuit differs somewhat from that used for the basic full wave circuit. Typically, a regulated power supply is designed to provide a constant output voltage for a wide range of load currents up to some maximum value. The exact specifications are determined by the device or devices that are to be powered by the supply. The output voltage is equal to the Zener voltage, so the output voltage specification dictates the value of Vz . The other component value to be set is usually the peak voltage of the secondary winding of the transformer. One commonly used rule of thumb is to make this value approximately 30-50% (or more) higher than the desired output voltage. Recall that when a filter capacitor is used at the output of a full-wave rectifier, the voltage across the capacitor approximately equals the peak voltage of the secondary minus two diodes voltage drops. The 30-50% rule of thumb helps to ensure that there is enough voltage "headroom," or "buffer," between the output voltage of the rectifier and the Zener voltage. The headroom is necessary to ensure that sufficient current flows through the Zener diode to maintain it in its reverse breakdown region of operation, even at maximum load current.

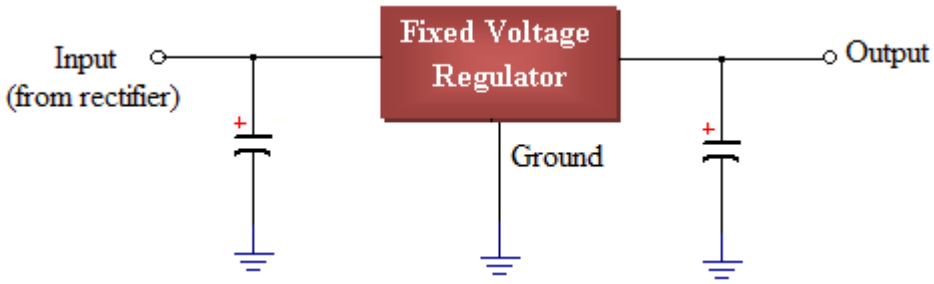
7. 3. IC Regulators

While filters can reduce the ripple from power supplies to a low value, the most effective filter is combination of a capacitor-input filter used with an *integrated circuit* (*IC*) voltage regulator. An integrated circuit regulator is a device that is connected to the output of a filtered rectifier and maintains a constant output voltage despite changes in the input, the load or the temperature. The

capacitor-input filter reduces the input ripple to the regulator to an acceptable level. The combination of a large capacitor and an IC regulator is inexpensive and helps produce an excellent small power supply.

The most popular IC regulator have three terminals; an input terminal, an output terminal, and a reference (or adjust) terminal. The input to the regulator is first filtered with a capacitor to reduce the ripple to less than 10%. The regulator further reduces the ripple to a negligible amount. In addition, most regulators have an internal voltage reference, short-circuit protection, and thermal shut down circuitry. They are available in a variety of voltages, including positive and negative outputs, and can furnish a constant output of one or more amps of current with high ripple rejection. IC regulators are available that can supply load currents of over 5 A.

Three-terminal regulators designed for a fixed output voltage require only external capacitors to complete the regulation portion of the power supply.



Filtering is accomplished by a large-value capacitor between the input and ground. Sometimes a second small-value input capacitor is connected in parallel, especially if the filter capacitor is not close to the *IC,* to prevent oscillation. This capacitor needs to be located close to the *IC*. Finally, an output capacitor (typically 0.1µF to 1.0µF) is placed in parallel with the output to improve the transient response.

7. 3. 1. 78xx Series voltage regulator

The 78xx (sometimes L78xx, LM78xx, MC78xx...) is a family of three-terminal self-contained fixed linear voltage regulator integrated circuits. The 78xx family is commonly used in electronic circuits requiring a regulated power supply due to their ease-of-use and low cost. The xx is replaced with two digits and stand for the output voltage; thus, the 7805 has a +5 volt output, while the 7812 produces +12 volts). The 78xx series are positive voltage regulators: they produce a voltage that is positive relative to a common ground.

78xx ICs have three terminals and are commonly found in the TO220 form factor, although smaller surface-mount and larger TO3 packages are available. These devices support an input voltage anywhere from a few volts over the intended output voltage, up to a maximum of 35 to 40 volts depending on the maker, and typically provide 1 or 1.5 amperes of current (though, smaller or larger packages may have a lower or higher current rating).

1. Input
2. Gound
3. Output

Figure 7-16: Typical 78xx voltage regulator with pin configuration

There are common configurations for 78xx ICs that are available with various output voltage and can supply up to 1 A of load current (with adequate heat sinking). The 7805 is common, as its regulated 5 volt supply provides a convenient power source for most TTL components. Each device in this series has minimum input voltage to be maintained to get regulated output as indicated in the table 7-2.

IC Part Number	Output voltage (V)	Minimum Input Voltage (V)
7805	+5	7.3
7806	+6	8.3
7808	+8	10.5
7810	+10	12.5
7812	+12	14.6
7815	+15	17.7
7818	+18	21.0
7824	+24	27.1

Table 7-2: 78xx series common voltage configuration with their minimum input voltage

Less common are lower-power versions such as the LM78Mxx series (500 mA) and LM78Lxx series (100 mA) from National Semiconductor. Some devices provide slightly different voltages than usual, such as the LM78L62 (6.2 volts) and LM78L82 (8.2 volts) as well as STMicroelectronics L78L33ACZ (3.3 volts).

Note: There are some ICs that have close similar numbering with 78xx that you don't have to confound when you are selecting voltage regulators since their working principle is not the same. This includes

- The LM78S40 from National Semiconductor is not part of the 78xx family since it does not use the same design. It is a component in switching regulator designs, and is not a linear regulator like other 78xx devices.
- The 7803SR from Datel is a full switching power supply module (designed as a drop-in replacement for 78xx chips), and not a linear regulator like the 78xx ICs.

Part list

No	Item	Specifications	Quantity
1	Diode	1N4001 rectifier diode	4
2	Capacitor	470µF/50V electrolytic capacitor	1
3	Capacitor	1µF/50V electrolytic capacitor	2
4	Voltage regulator	LM7805	1
5	9VAC, 50Hz supply	Function generator (Agilent 33120A)	1
6	Oscilloscope	Digital oscilloscope (Agilent 54622D)	1
7	Voltmeter	Digital Multimeter	1

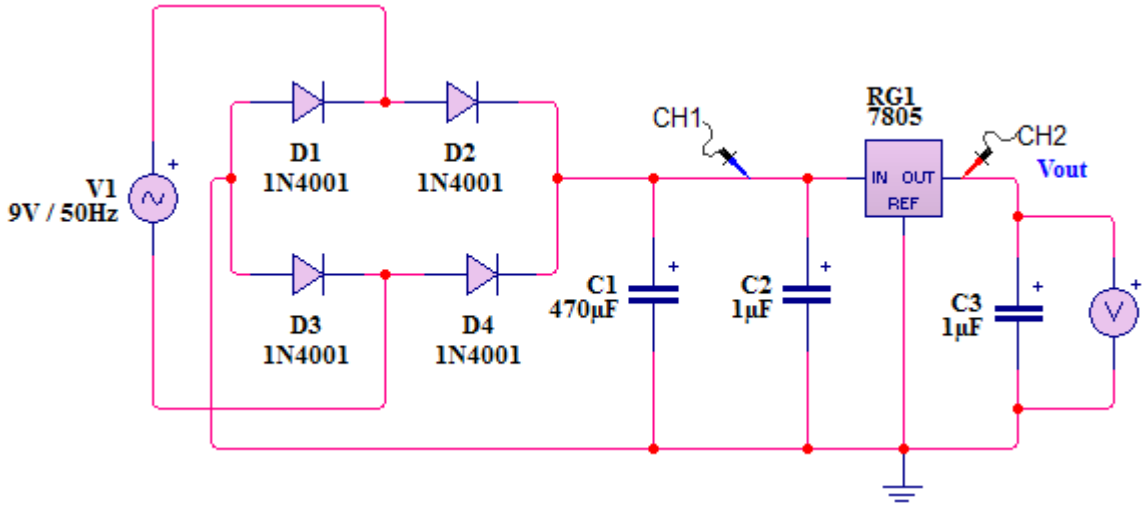


Figure 7-17: Circuit for 7805 used as voltage regulator

Procedure

1. Choose four 1N4001 diodes, one 470µF/50V electrolytic capacitor, two 1µF/50V electrolytic capacitors and one LM7805 positive voltage regulator.
2. Connect the circuit as illustrated in the figure 7-18.
3. Switch on the function generator and set the output frequency to 50 Hz and the output amplitude to 9 V rms sinusoidal.
4. Connect the output of the function generator to the input of the rectifier and connect channel 1 of the oscilloscope to the output of the rectifier to observe unregulated voltage just direct to the output of the rectifier. Connect channel 2 of the oscilloscope to the output of regulator to visualize regulated voltage. Again set the multimeter in Volt settings 20V scale and connect it to the output of the regulator to measure the regulated output voltage.

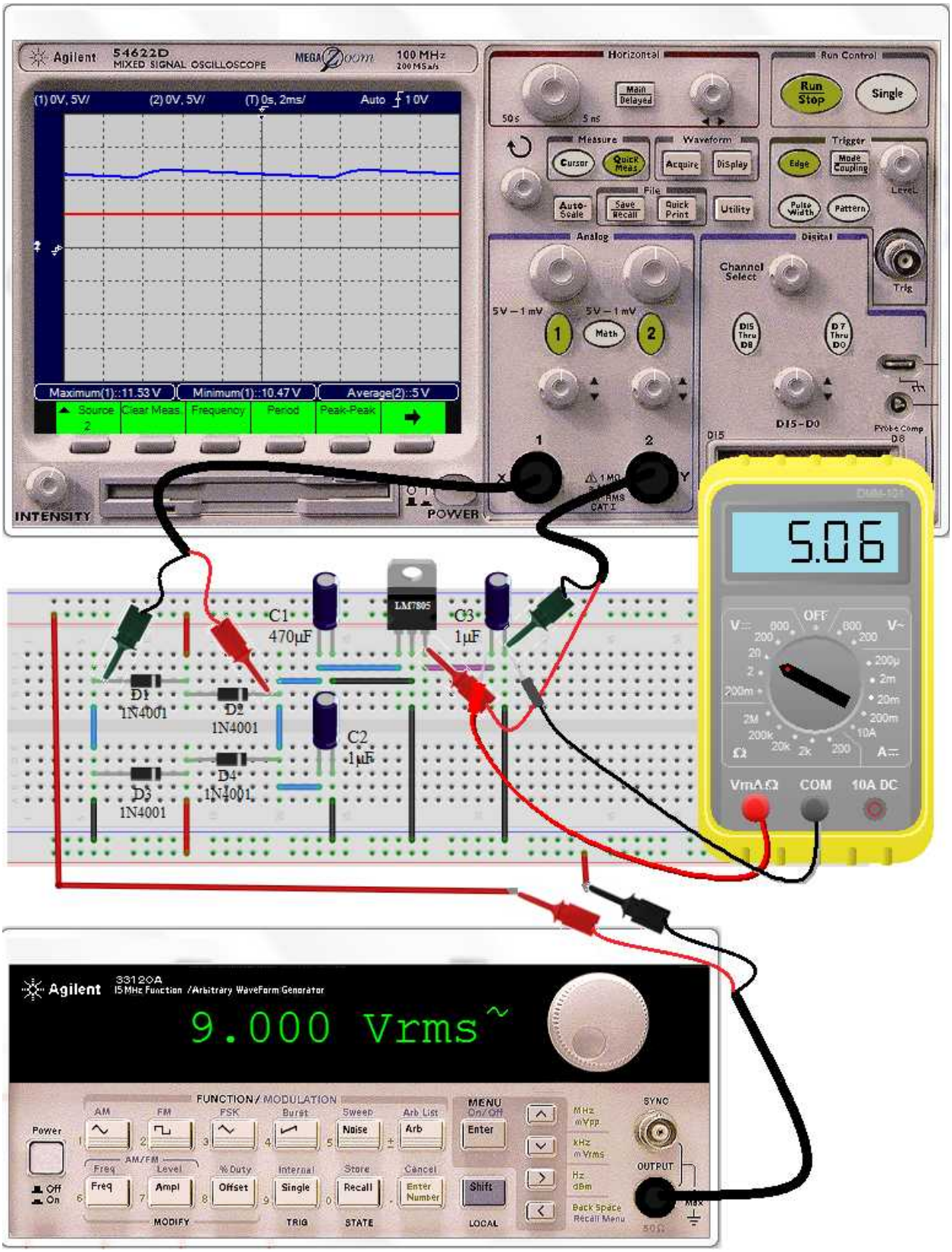


Figure 7-18: Circuit for 7805 used as voltage regulator, real world circuit connection

5. Press measure button from oscilloscope and measure V_{max} and V_{min} at channel 1 (to keep an eye on voltage variation) and V_{av} at channel 2.

7. 3. 2. Increasing the output voltage of 78xx regulator

The +5V output of the 7805 is referenced to the "ground, Gnd" or "0v" terminal. If we increase this pin-2 terminal voltage from 0V to 3V for example, then the output would also rise by an additional 3 volts providing there was sufficient input voltage.

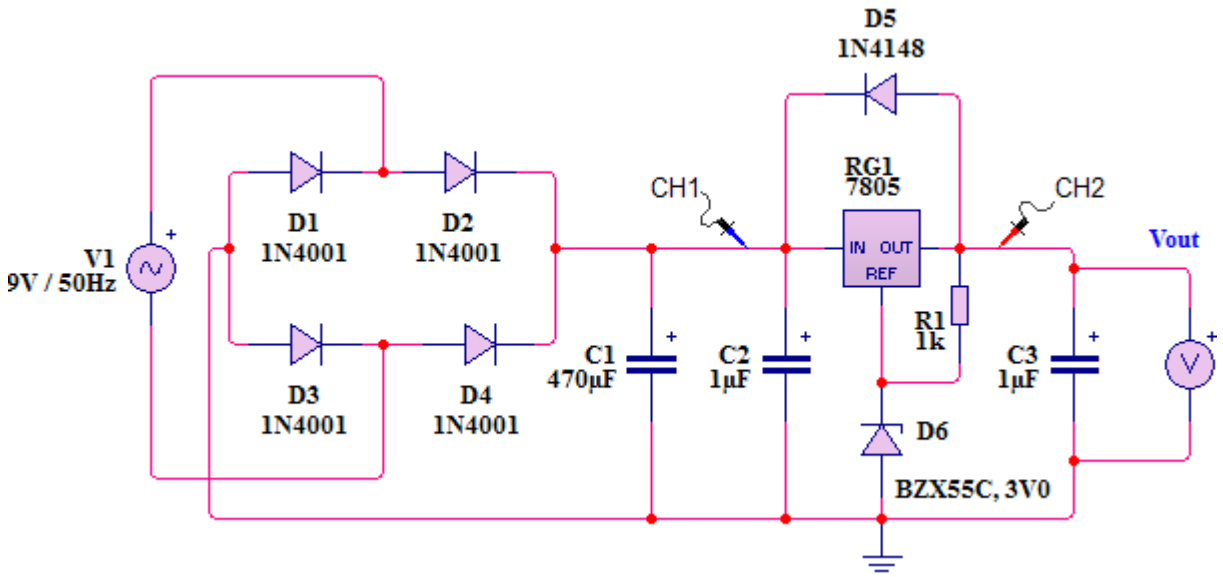


Figure 7-19: Circuit example for increasing the output voltage of 78xx

Then by placing a small 3 volt Zener diode between pin-2 of the regulator and ground, we can make a 7805 (5V) regulator produce a +8 volts output voltage.

Working Principle of the Circuit

The 3V Zener diode requires a reverse bias current of around 5mA to maintain an output with the regulator taking about 0.5mA. This total current of 5.5 mA is supplied via resistor "R_1" from the output pin-3. So the value of the resistor required for a 7805 regulator will be: R = 5V/5.5mA = 910 Ohm (1KΩ using standard resistor value). The feedback diode, D5 connected across the input to output terminals is for protection and prevents the regulator from being reverse biased when the input supply voltage is switched OFF while the output supply remains ON or active for a short period of time due to a large inductive load such as a solenoid or motor.

Then, we can use 3-terminal voltage regulators and a suitable Zener diode to produce a variety of fixed output voltages from our previous circuit power supply ranging from +5V up to +12V. But we can improve on this design by replacing the fixed voltage regulator with a variable voltage regulator such as the LM317T that we are going to discuss later.

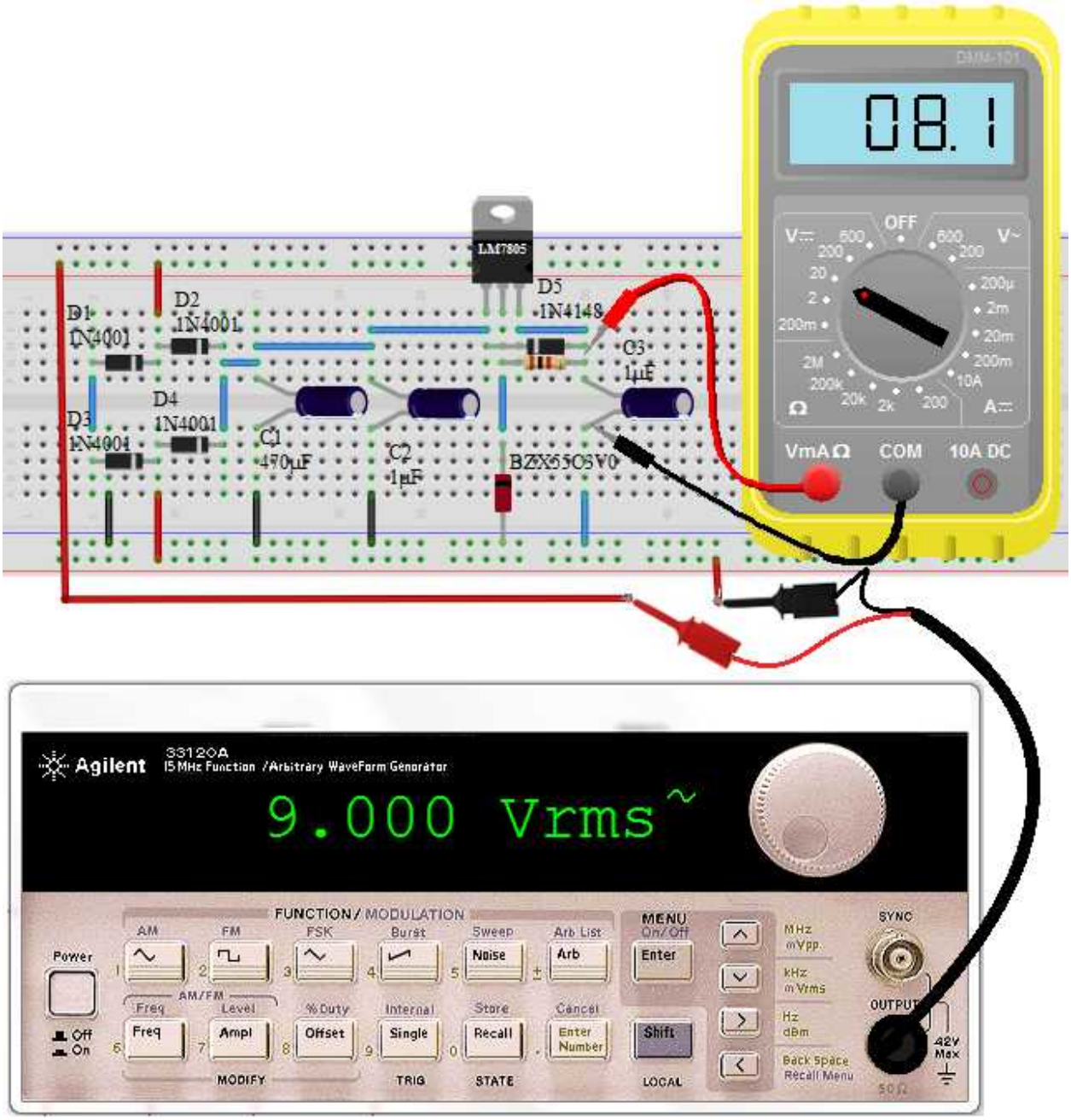


Figure 7-20: Circuit example for increasing the output voltage of 78xx, real world circuit connection

Related Fixed Positive Regulators ICs

The LM7800C has the same features as LM140/LM340A/LM340. These are monolithic 3-terminal positive voltage regulators employ internal current-limiting, thermal shut down and safe-area compensation, making them essentially indestructible. If adequate heat sinking is provided, they can deliver over 1.0A output current. They are intended as fixed voltage regulators in a wide range of applications including local (on-card) regulation for elimination of noise and distribution problems associated with single-point regulation. In addition to use as fixed voltage regulators, these

devices can be used with external components to obtain adjustable output voltages and currents.

Advantage and Disadvantage of 78xx Series Regulator

Advantages	Disadvantages
• 78xx series ICs do not require additional components to provide a constant, regulated source of power, making them easy to use, as well as economical and efficient uses of space. Other voltage regulators may require additional components to set the output voltage level, or to assist in the regulation process. Some other designs (such as a switched-mode power supply) may need substantial engineering expertise to implement.	• The input voltage must always be higher than the output voltage by some minimum amount (typically 2.5 volts). This can make these devices unsuitable for powering some devices from certain types of power sources (for example, powering a circuit that requires 5 volts using 6-volt batteries will not work using a 7805).
• 78xx series ICs have built-in protection against a circuit drawing too much power. They have protection against overheating and short-circuit, making them quite robust in most applications. In some cases, the current-limiting features of the 78xx devices can provide protection not only for the 78xx itself, but also for other parts of the circuit.	• As they are based on a linear regulator design, the input current required is always the same as the output current. As the input voltage must be always higher than the output voltage, this means that the total power (voltage multiplied by current) going into the 78xx will be more than the output power provided. The extra input power is dissipated as heat. This means both that for some applications an adequate heatsink must be provided, and also that a (often substantial) portion of the input power is wasted during the process, rendering them less efficient than some other types of power supplies. When the input voltage is significantly higher than the regulated output voltage (for example, powering a 7805 using a 24 volt power source), this inefficiency can be a significant issue.

Table 7-3: Advantages and disadvantages of 78xx series regulator

7. 3. 3. 79xx Series Voltage Regulator

The 79xx devices which are complementary negative voltage regulators. The negative output versions of the same regulator as 78xx are numbered as the 79xx and has also common configurations, including 7905 (–5 volt), 7906 (–6 volt), 7908 (–8 volt), 7909 (–9 volt), 7910 (–10 volt), 7912 (– 12 volt), 7915 (–15 volt), 7918 (–18 volt), and 7924 (–24 volt) versions.

1. Gound
2. Input
3. Output

Figure 7-21: 79xx pictorial with pinout

78xx and 79xx ICs can be used in combination to provide positive and negative supply voltages in the same circuit. This gives a dual polarity power supply.

7. 3. 4. Dual polarity power supply

Dual polarity power supply consists of a circuit capable to produce both positive voltage and negative voltage. This can be achieved by using two sources of DC voltage connected in series and by taking ground terminal at junction point of positive and negative terminals of the two batteries thereafter, the remaining terminals serve as positive supply and negative supply as shown in the circuit of the figure 7-23.

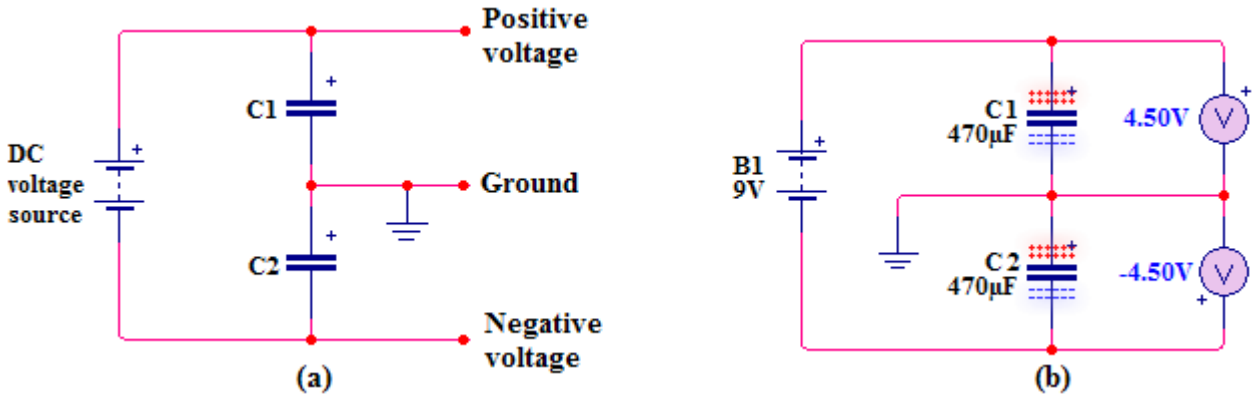


Figure 7-22: Designing dual polarities power supply using equal pair capacitors; (a) Circuit principle, (b) Circuit example.

The other method for getting dual polarity is using both positive and negative voltage regulator (78xx and 79xx voltage regulators) having the same supply (rectifier for example) from a pair connected capacitors as.

In principle, when pair equal capacitors are connected in series and supplied by a dc source, their point of connection serves as ground and the positive voltage and negative voltage are taken directly to the terminal of the main supply respectively.

It is with this property used to get dual polarity when the main dc source is rectifier but has the main disadvantage that the voltage reaching on any polarity side is halved with respect to the input main supply. This principle is shown in the circuit of the figure 7-22.

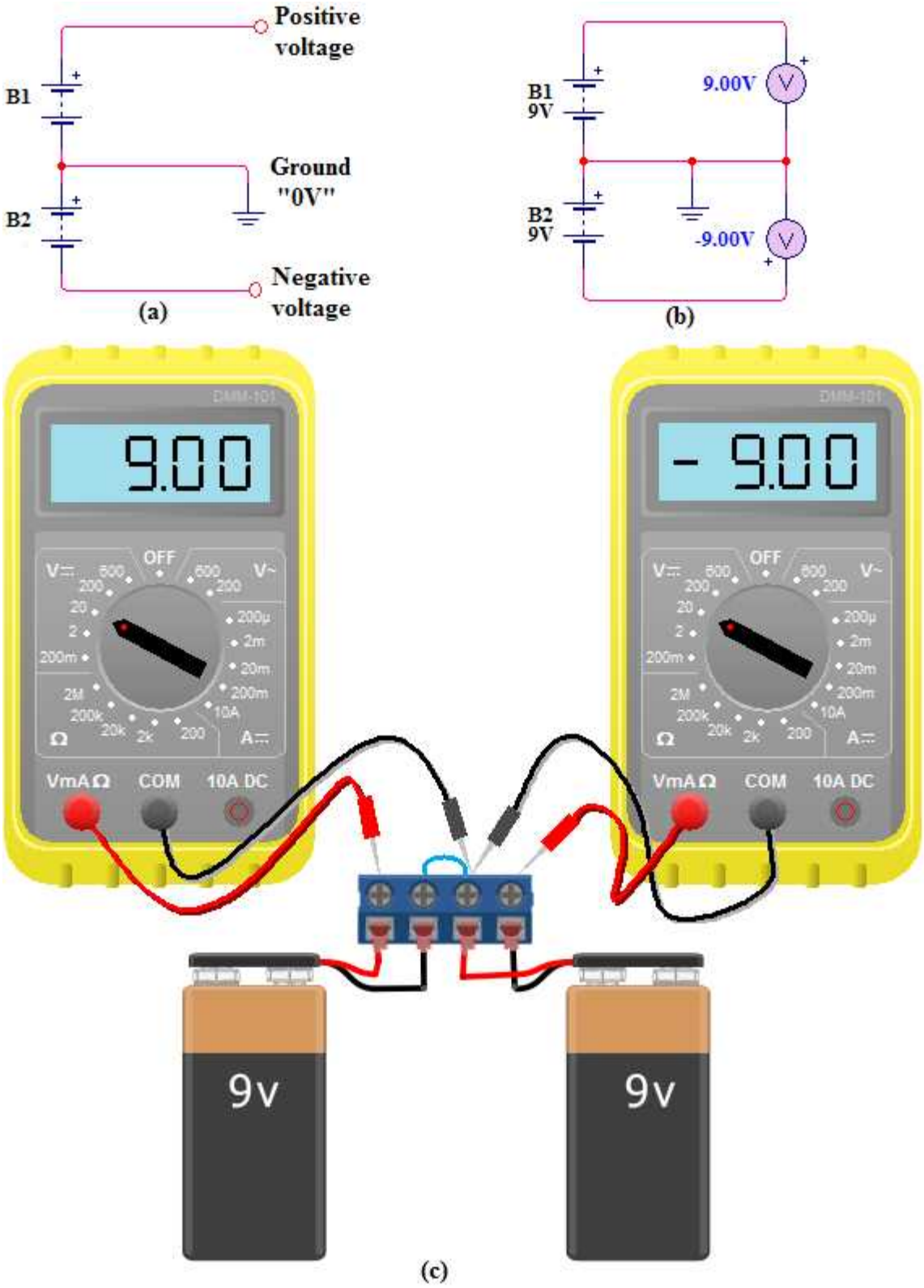


Figure 7-23: Dual polarity power supply using two dc sources; (a) Circuit principle, (b) Circuit example, (c) Circuit example real world connection

Dual Polarity Using Full-Wave Bridge Rectifier

As mentioned earlier, dual polarity voltage can be constructed from a rectifier as dc source and by using both positive and negative regulators. The circuit of figure 7-24, shows an example of the dual polarity supply from a full wave bridge rectifier.

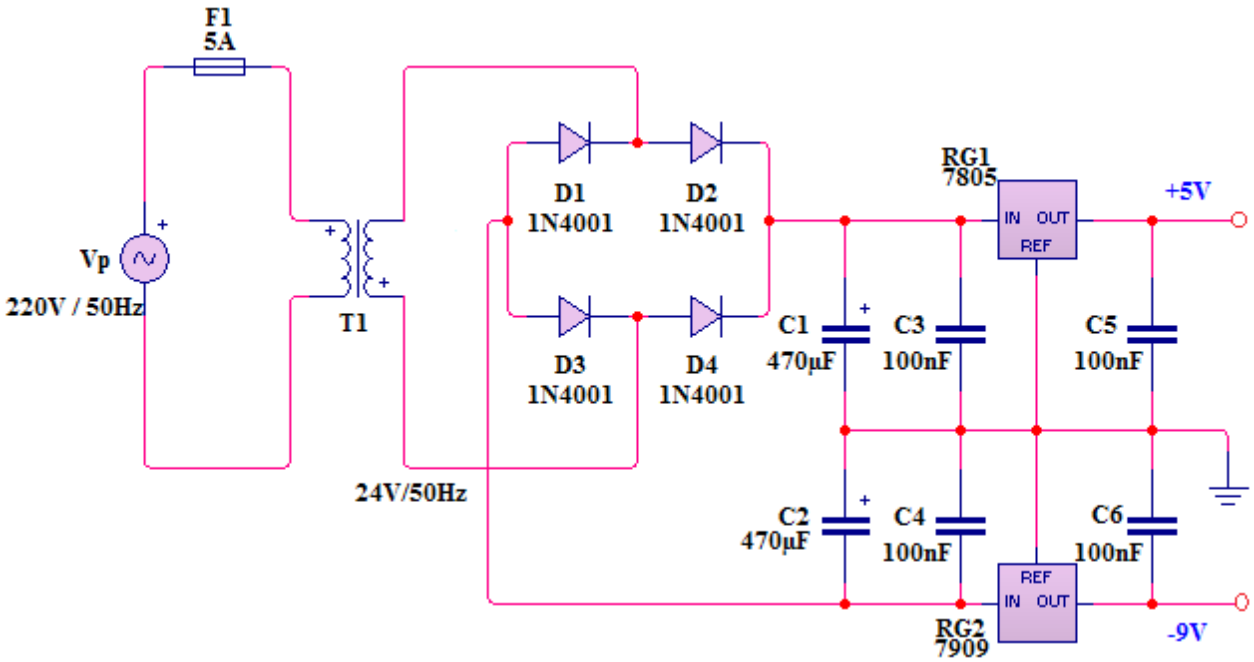


Figure 7-24: Example for dual polarity supply using bridge rectifier

Working Principle of the Circuit.

Transformer T1 reduces the wall outlet voltage to a convenient level, 220V ac to 24V ac for this example, which will supply a peak voltage of 24V*√2 = 33.9V to the rectifiers. The peak of the secondary of transfomer should be slightly greater than the desired regulated voltage so as to compansate for diode drop and regulator dropout. The peak secondary is halved (minus diode drop) to get dual polarity at the terminals of the capacitors (C_1, C_2). Diodes D_1, D_2, D_3 and D_4 form a rectifying circuitry, output of which is pulsing DC waveform. Capacitor C_1 and C_2 are used for filtering output DC waveform, whereas capacitor C_3 and C_4 are used to improve transient response and filtering high frequency line noise. Both RG_1 and RG_2 are fixed regulators. RG_1 is a positive regulator capable to provide +5V dc, whereas RG_2 is negative regulator supplying –9V dc. C_5 and C_6 stiffen the output voltage and reduce the output impadance. Note that this is an example, for any required voltages, you can change the value of regulators and use any other transformer accordingly.

Multiple Output Dual Polarity using Center-Tapped Transformer Full Wave Rectifier

Some of the units within the circuit require different voltages and currents. These different voltages form the groups depending on their level and polarity. These groups are the so-called “multiple power supply rails”.

They are not fully independent; they are all connected to a single high-current source inside the power supply, but have separate output. This can be built easily for delivering up to 1 ampere with the appropriate choice of center tapped transformer and 3-terminal voltage regulator pairs at +/- 5V, +/- 9V, +/- 12V, and so on. The 3-terminal pair of regulators you choose: 7805 & 7905, 7809 & 7909, 7812 & 7912, 7815 & 7915, 7818 & 7918 or 7824 & 7924. The + and – regulators do not have to be matched; you can for example, use a +5v and –9V pair. Example circuit is shown in figure 7-25.

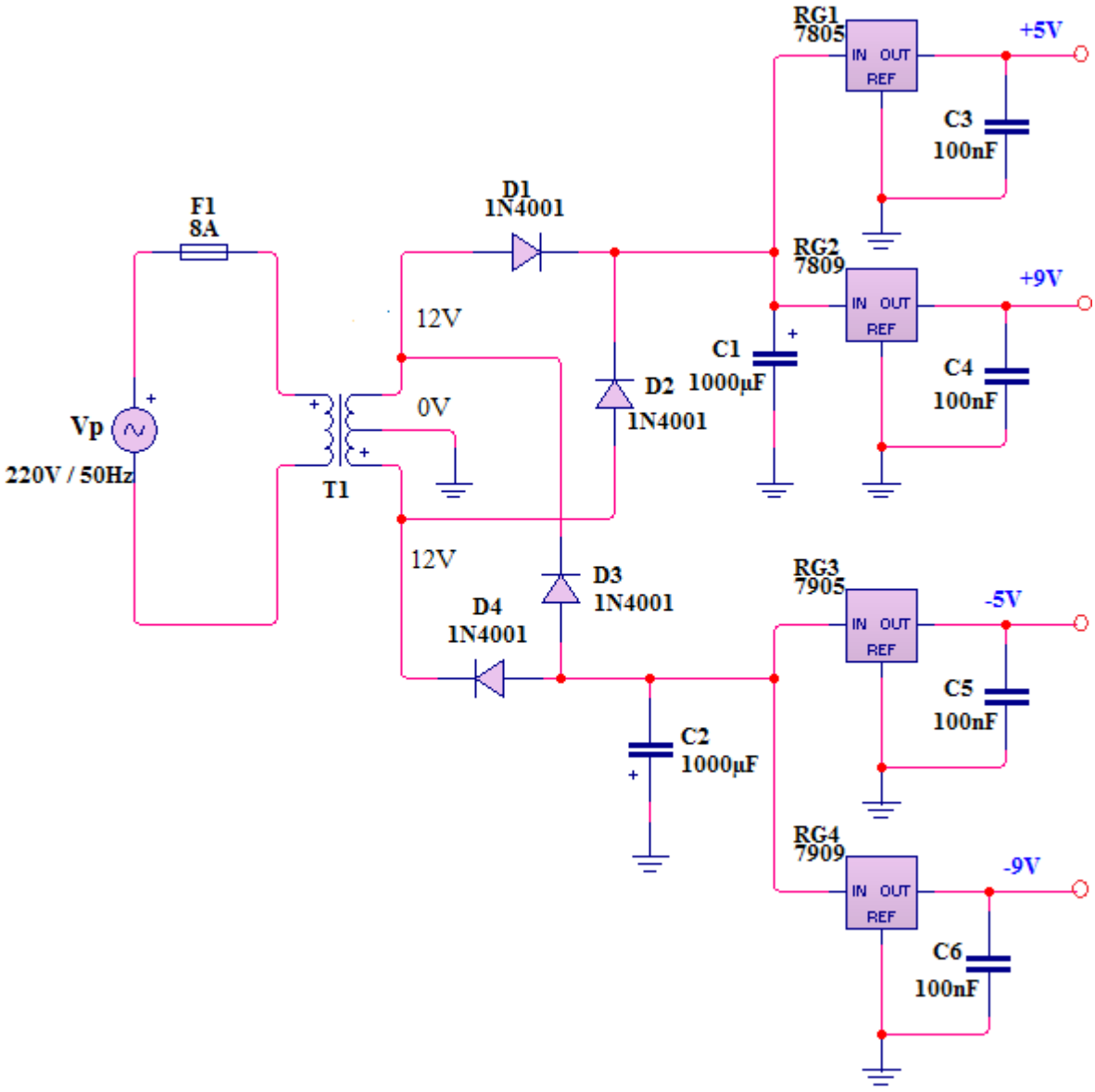


Figure 7-25: Example for dual polarity supply with multiple outputs using center-tapped full wave rectifier

Working Principle of the Circuit

Transformer T1 reduces the wall outlet voltage to a convenient level, 220V ac to 24V ac for this example, which will supply a peak voltage of 12V*√2 = 16.97V to the rectfiers. The total sec-

ondary voltage is 24V ac 50Hz, the center tap serves as ground thus having 12V at positive half cycle of the secondary voltage and 12V at the negative half cycle. The peak of the secondary of transfomer should be slightly greater than the desired regulated voltage so as to compansate for diode drop and regulator dropout. Diodes D_1 through D_4 form a rectifying circuitry, output which is pulsing DC waveform. D_1 and D_2 make positive pulsing and supply positive regulators RG_1 and RG_2. D_3 and D_4 compose negative pulsing and supply negative regulators RG_3 and RG_4. Capacitor C_1 and C_2 are used for filtering output DC waveform, whereas capacitor C_3 and C_4 stiffen the output voltage and prevent any high frequency present at the output. Regulators RG_1 through RG_4 are fixed regulators. RG_1 and RG_2 are positive regulators capable to provide +5V dc and +9V dc respecitively, whereas RG_3 and RG_4 are negative regulator supplying –5V dc and –9V dc respectively. For any required regulated voltage, you can change the value of regulators and use any other transformer accordingly.

Application of Dual Polarity Supply

Dual polarity is more often used for powering op-amp circuits, as well as other circuits that require a dual supply voltage. The other applications of dual polarity power supply are brushless DC motor testing, aircraft ground support system, hybrid vehicle systems, water treatment.

7. 3. 5. Variable voltage power supply

Another type of three-terminal regulator is adjustable regulator. There are a variety of ICs for variable regulator but the most used include:

Positive Variable Voltage Regulator

The most encountered positive adjustable voltage regulator ICs include

- LM350: The LM350 is an adjustable 3-terminal positive voltage regulator capable of supplying an excess of 3.0A over an output voltage range of 1.2V to 33V
- LM117/LM317: The LM317 is an adjustable 3-terminal positive voltage regulator capable of supplying in excess of 1.5 A over an output voltage range of 1.2 V to 37 V. This voltage regulator is exceptionally easy to use and requires only two external resistors to set the output voltage. Further, it employs internal current limiting, thermal shut down and safe area compensation, making it essentially blow-out proof.

  The LM317 serves a wide variety of applications including local, on card regulation. This device can also be used to make a programmable output regulator, or by connecting a fixed resistor between the adjustment and output, the LM317 can be used as a precision current regulator.

Negative Variable Voltage Regulator

The LM137/LM337-N are adjustable 3-terminal negative voltage regulators capable of supplying in excess of −1.5A over an output voltage range of −1.2V to −37V. These regulators are exceptionally easy to apply, requiring only 2 external resistors to set the output voltage and 1 output capacitor for frequency compensation. The circuit design has been optimized for excellent regulation and low thermal transients. Further, the LM137 series features internal current limiting, thermal shut down and safe-area compensation, making them virtually blowout-proof against overloads.

The LM137/LM337-N serve a wide variety of applications including local on-card regulation, programmable-output voltage regulation or precision current regulation. The LM137/LM337-N are ideal complements to the LM117/LM317 adjustable positive regulators.

Experiment 7-4: Design a variable positive voltage using LM317

The LM317T is a fully adjustable 3-terminal positive voltage regulator capable of supplying 1.5 amps with an output voltage ranging from about 1.25 to 30 volts. By using the ratio of two resistances, one of a fixed value and the other variable, can be used to set the output voltage to the desired level with a corresponding input voltage between 3 and 40 volts. The output voltage of the LM317T is determined by ratio of the two feedback resistors which form a potential divider network across the output terminal as shown in figure 7-26.

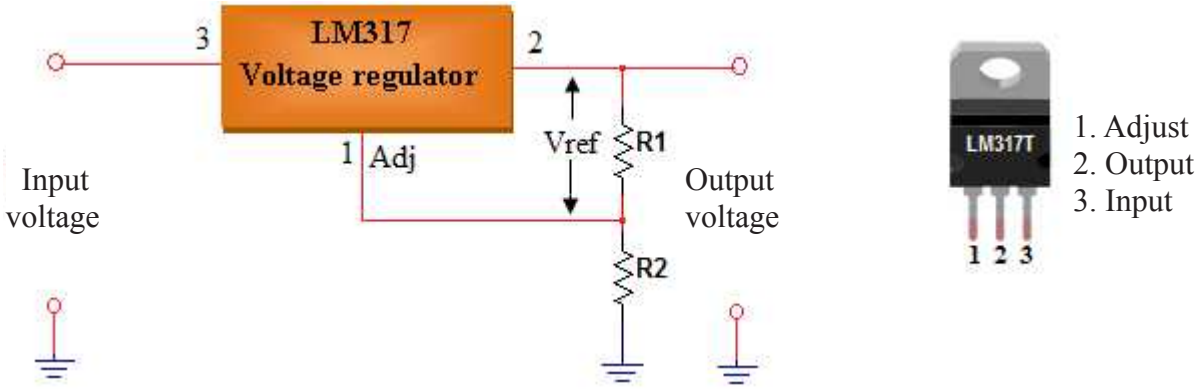


Figure 7-26: Variable voltage regulator base circuit using LM317

chap 7

The voltage across the feedback resistor R_1 is a constant 1.25 V reference voltage, V_{ref} produced between the "output" and "adjustment" terminal. This produces a constant current in R_1 of V_{ref}/R_1. Also, the LM317 has very good load regulation providing that the minimum load current is greater than 10 mA. So to maintain a constant reference voltage of 1.25 V, the minimum value of feedback resistor R_1 needs to be 1.25V/10mA = 120 Ω and this value can range anywhere from 120 ohms to 1,000 ohms with typical values of R_1 being about 220Ω to 240 Ω for good stability. Therefore, For R_1 = 220 Ω, the current through R_1 is 1.25V/220 Ω = 5.6mA. Since the reference voltage across resistor R_1 is constant and neglecting the very small current through adjustment terminal, a constant current I will flow through the other resistor R_2. The output voltage is taken across both R_1 and R_2 and is found from the equation:

$$V_{out} = 1.25V\ (R_1 + R_2/R_1)$$

Note that the output voltage from the power supply is the regulator's 1.25V multiplied by a ratio of resistances.

Obviously the input voltage, V_{in} must be at least 2.5 volts greater than the required output voltage to power the regulator.

If we know the value of the required output voltage, V_{out} and the feedback resistor R_1 is say 220 ohms, then we can calculate the value of resistor R_2 from the above equation. For example, our original output voltage of 9V would give a resistive value for R_2 of:

$R_2 = R_1*[(V_{out}/1.25) - 1]$

$= 220*[(9/1.25) - 1]$

$= 1{,}346\Omega$ or $1{,}500\Omega$ (1K5 if we choose the nearest preferred value from resistor pack)

Of course in practice, resistor R_2 would normally be replaced by a potentiometer so as to produce a variable voltage power supply, or by several switched preset resistances if several fixed output voltages are required.

Part list

No	Item	Specifications	Quantity
1	Diode	1N4001 rectifier diode	4
2	Capacitor	1000µF/50V electrolytic capacitor	1
3	Capacitor	1µF/50V electrolytic capacitor	2
4	Variable Voltage regulator	LM317	1
5	12VAC, 50Hz supply	Transformer 220V/6-0-6V, 50Hz, 2A	1
6	R1 resistor	220 Ω fixed resistor	1
7	Voltmeter	Multimeter	1
8	R2 resistor	1.5 K Ω (2.5K) Potentiometer	1

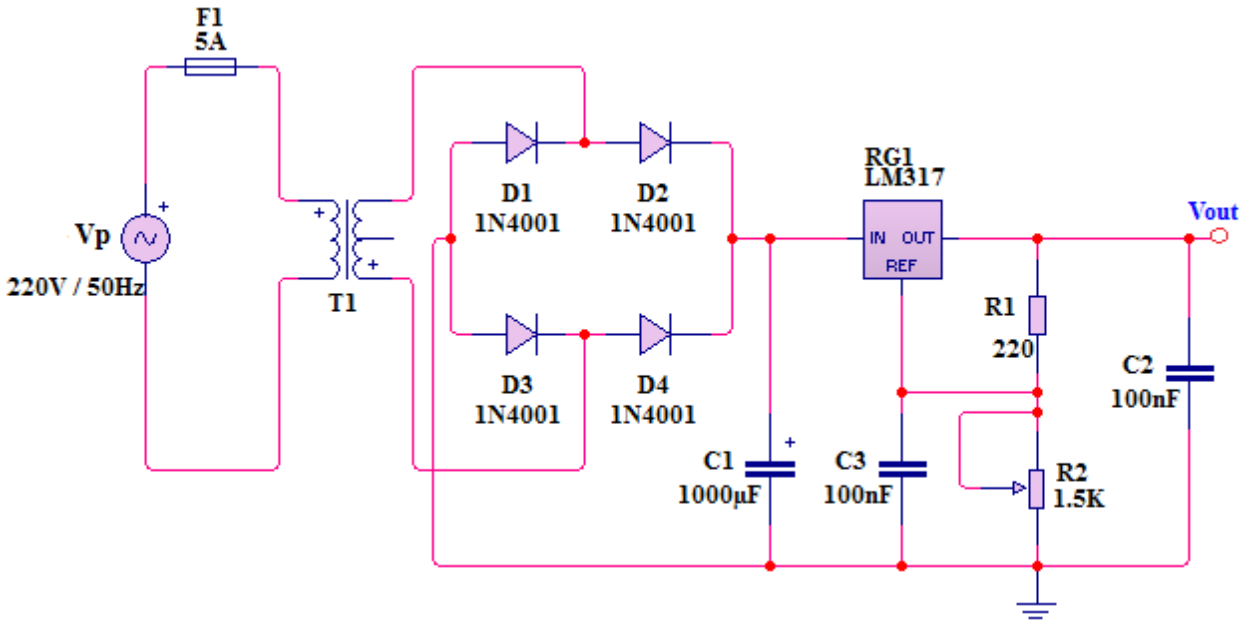


Figure 7-27: Circuit for variable voltage regulator using LM317

Working Principle of the Circuit

Transformer T_1 reduces the wall outlet voltage to a convenient level, 220V ac to 12V ac for this example, which will supply a peak voltage of $12V*\sqrt{2} = 16.97V$ to the rectfiers. The total secondary voltage is 24V ac 50Hz, the center tap serves as ground thus having 12V at positive half cycle of the secondary voltage and 12V at the negative half cycle. The peak of the secondary of trans-

fomer should be slightly greater than the desired regulated voltage so as to compansate for diode drop and regulator dropout.

Diodes D_1 through D_4 form a rectifying circuitry, output of which is pulsing DC waveform. C_1 is electrolytic capacitor used for filtering output DC waveform, whereas C_2 stiffen the output voltage and prevent any high frequency present at the output. Capacitor C_3 improve the regulators' ripple rejection from 65dB to 80dB (typical) by preventing ripple voltage from being amplified at the output of the regulator. Regulator RG_1 is positive variable regulator capable to supply variable output voltage from 1.25V up to 37V dc, for the case of this circuit, when R_2 is set to the minimum (zero) resistance, the output is 1.25V, when R_2 is set to the maximum the output is nearly 10.5V. For any higher regulated voltage, you can use transformer with high secondary voltage.

Procedure

1. Choose 220Ω fixed resistor and 1.5KΩ (2.5KΩ) potentiometer, 1000µF/50V electrolytic capacitor, 100nF (104) ceramic capacitor and LM317 positive variable regulator and 220V/12V 50Hz transformer. You can use 220/24V 50Hz transformer instead.
2. Connect the circuit as illustrated in the figure 7-28.
3. Check the proper connectivity of the circuit and measure the secondary voltage of the transformer using multimeter set in ac voltage settings.
4. Connect the secondary of the transformer to the circuit and set multimeter in dc setting to measure the secondary voltage.
5. Use the potentiometer knob to vary the output voltage available at pin 2 of the regulator and ground.

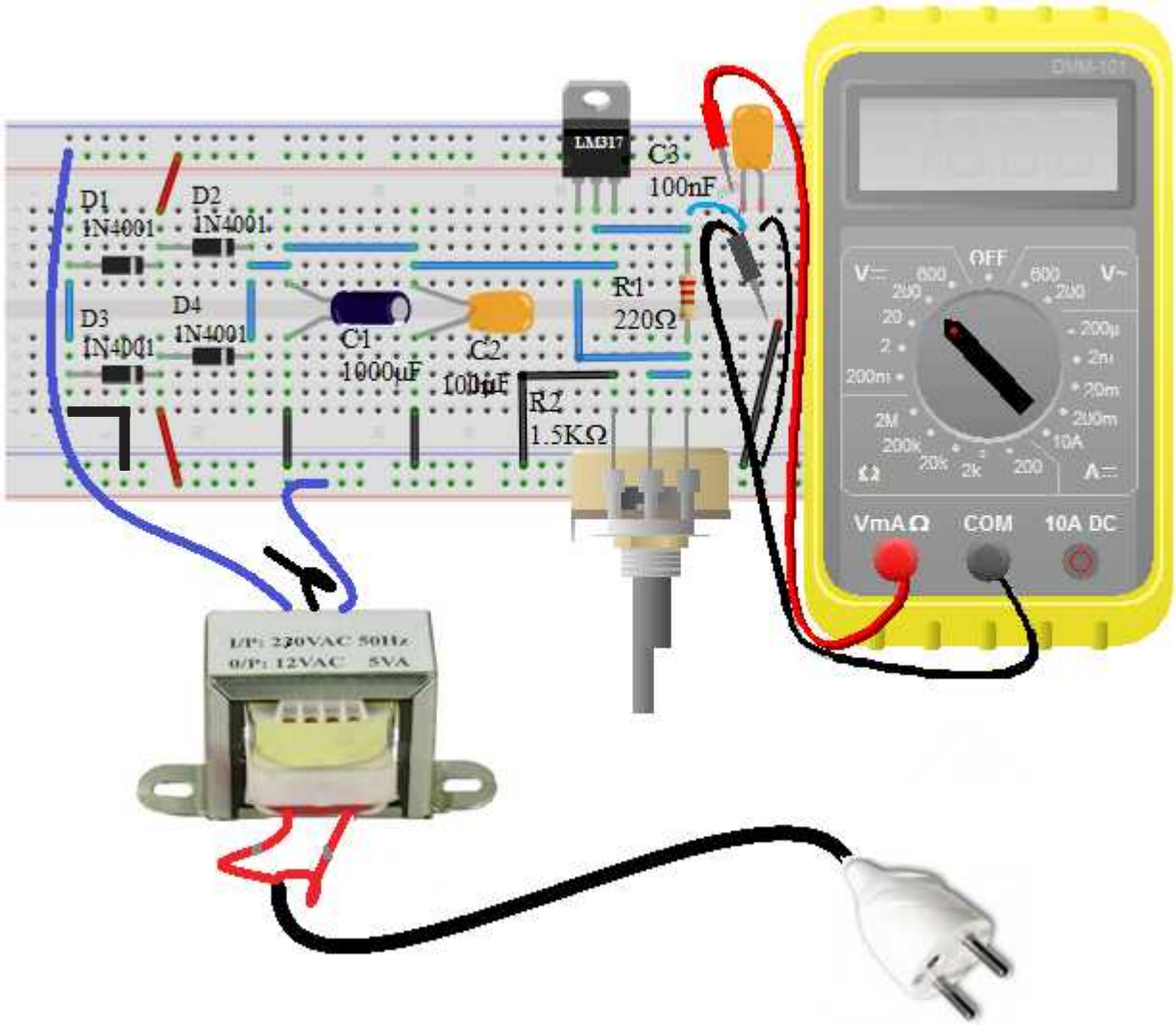


Figure 7-28: Circuit connection for variable voltage regulator using LM317

Safety point

Resistors can become very hot in normal operation. To avoid a burn, do not touch a circuit component while the power is connected to the circuit. After has turned off, allow time for components to cool down.

Chapter eight

Voltage Clipper

Objectives

When you studied this chapter, you should

- Have an understanding of the working principle of the voltage clipper
- Be capable to design a voltage limiting to any desired DC level
- Have an understanding of the voltage clipper and their applications

Further reading
Study aids for this chapter are available at the companion website
http://www.allaboutcircuits.com/vol_3/chpt_3/6.html

A clipper (also called limiter) is an electronic circuit which cuts off, limits, removes or prevents some portion of the wave form (positive or negative amplitude, or both of input signal voltage) above or below a specified voltage level. A diode is a key element in electronic circuit clipper and its position, presence or absence of DC bias determines the type of clipper used. Mainly the clipper circuits are of the following types.

1. Series positive clipper
2. Series negative clipper
3. Shunt or parallel clipper
4. Dual (combination) Diode clipper
5. Zener clipper

8. 1. Series clipper

Series voltage clippers consist of a diode connected in series with a load.

8. 1. 1. Series positive clipper

A series positive clipper consists of a diode connected in series (anode connected to the input supply and cathode to the output load) with the output and this removes or clips the positive half completely. The diode acts as a series switch between the source and load.

Experiment 8-1. Series positive clipper

Build a circuit having 6V input AC supply and a diode connected in series to a load resistor. The required materials to build this circuit for experiment are listed below.

Part lists

No	Items	Specifications	Quantity
1	Oscilloscope	Agile oscilloscope 54622D	1
2	Diode	1N4002	1
3	Resistors	1kΩ	1
4	6VAC supply	Agilent Function generator 33120A	1
5	Breadboard	Prototyping board (RSR 03MB102)	1
6	Wire	22-gauge (0.33mm^2)solid wire	40cm

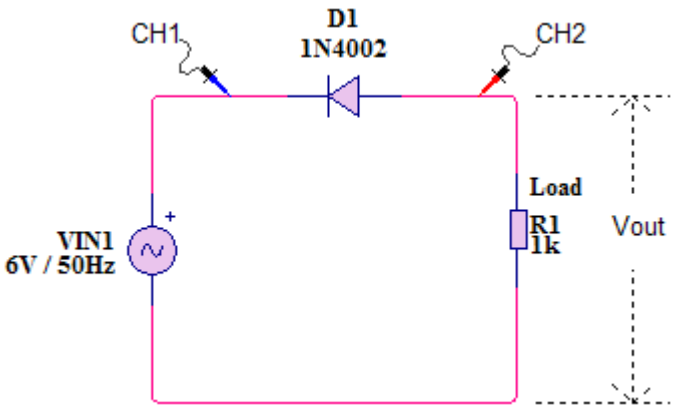


Figure 8-1: Series positive clipper circuit

Working Principle of the Circuit

During the positive half of the AC input voltage, the cathode of diode is positive with respect to its anode. This reverse biases the diode and it acts as an open switch therefore all the applied voltage drops across the diode and none across the resistor.

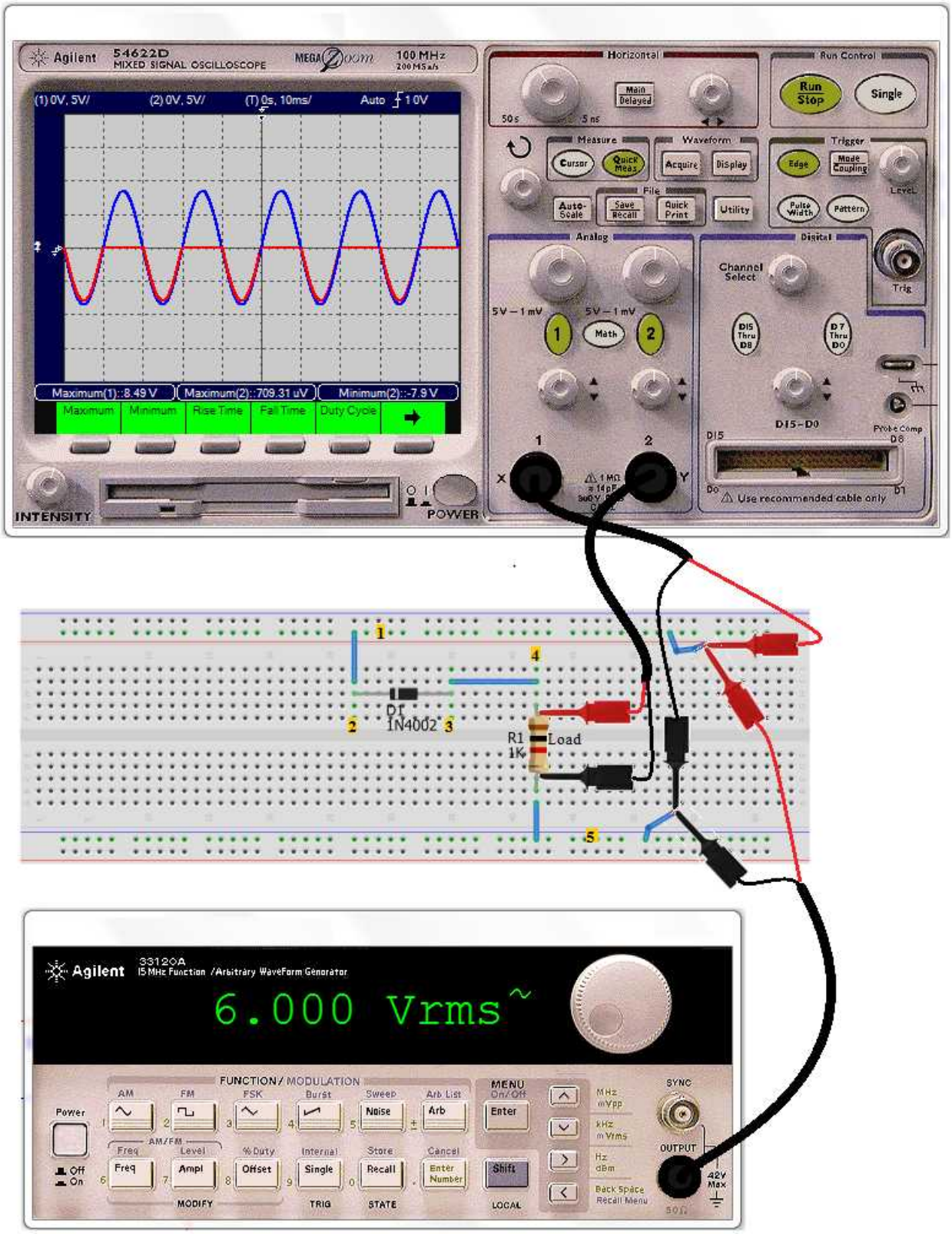


Figure 8-2: Series positive clipper, real world circuit connection

As a result of this, there is no output voltage during the positive half cycle of the input voltage, means that the positive half cycle of the output is limited to 0V thus,the circuit is called a positive Clipper. Here the diode is considered as a series switch between the source and load.

During the negative half cycle of the input AC voltage the anode of diode is positive with respect to the cathode. Therefore, it forward-biases the diode and it acts as a closed switch. Thus there is no voltage drop across the diode during the negative half cycle of the input voltage. All the input voltage is dropped across the resistor as shown in the output waveform.

Procedure

Connect AC supply to power bus and ground bus (1-5) of breadboard as illustrated in figure 8-2. Normally AC supply has no positive and negative polarities but in case a function generator takes a place of AC supply, consider red lead as positive and black lead as negative to avoide mistakes. Therefore red probe has to be connected to positive bus of breadboard(1) and black probe to negative bus of breadboard (5). Cathode of diode is connected to a positive power bus through a jumper wire (1-2). A load resistor is connected to the anode of diode (3-4) and to the ground or negative power bus (5). Before supplying the circuit it is better to check the connection.

Set function generator to 6V rms. If you are not using digital function generator which shows the value in digital format you can measure its output voltage using voltmeter set to AC mode. Set channel one and channel two (CH1 and CH2) of oscilloscope to 5Volt/div and to 10mSec/div vertical sensitivity and horizontal sensitivity respectively. The oscilloscope should be AC coupled to read the input waveform but should be DC coupled to read the output waveform.

You can adjust vertical sensitivity and horizontal sensitivity to make the wave take up most of the screen without chopping any of its amplitude off and in the easy way reading and calculation.

The input AC voltage waveform is displayed from channel one (CH1) of oscilloscope while the channel two (CH2) is showing the clipped wave on the load resistor.

As result shown from oscilloscope, the maximum input voltage is 8.49V while the maximum output voltage is 709.31uV or simply say zero volt and its minimum peak value is –7.9V. However a positive portion of the input wave is removed or clipped completely. Due to this reason the circuit is called series positive clipper.

8. 1. 2. Series positive clipper with bias

Sometimes it is desired to remove a small portion of positive half cycle of the signal voltage (input signal) in order to prevent it from exceeding a specific amplitude level. For this purpose a DC supply is inserted in a circuit. Depending on the orientation of battery, a circuit can either be a series positive clipper with a positive bias or a series positive clipper with a negative bias.

Experiment 8-2. Series positive clipper with bias

By using a 3VDC battery and 6VAC supply, build a circuit containing a diode connected in series with a combination of a battery and a resistor. Detailed items for such circuit are given in the list below.

Part lists

No	Items	Specifications	Quantity
1	Oscilloscope	Agile oscilloscope 54622D	1
2	6VAC supply	Agilent function generator 33120A	1
3	3VDC supply	1.5V AA cell x2	1
4	Resistors	1KΩ	1
5	Breadboard	Prototyping board (RSR 03MB102)	1
6	Connecting wire	22-gauge solid wire	40cm
7	Diode	1N4001	1

- **Series Positive Clipper with Positive Bias**

For series positive clipper with positive bias, the positive terminal of the battery is connected to the anode of diode through a load resistor as shown in figure 8-3.

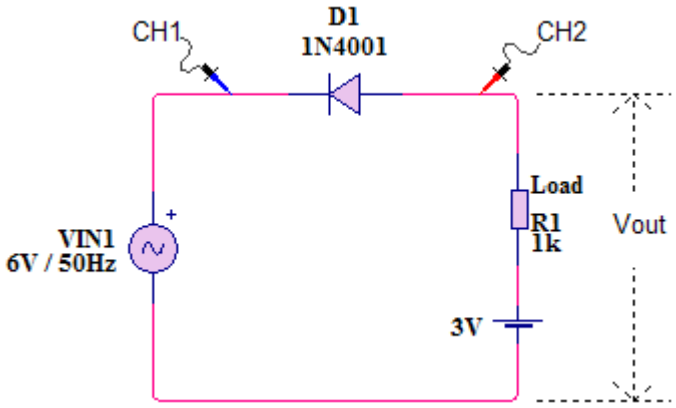


Figure 8-3: Series positive clipper with positive bias circuit

Procedure

Connect the circuit as illustrated in figure 8-4. The AC supply is connected to power bus and ground bus (1-6) of breadboard. The AC supply can be taken from the secondary of a transformer with this the polarity does not matter but in case of a function generator, consider red lead as positive and black lead as negative to avoid errors. Therefore the red probe has to be connected to a positive bus of breadboard(1) and black probe to a negative bus of breadboard (6). Cathode of diode is connected to a positive power bus through a jumper wire (1-2). A load resistor is connected to the anode of diode (3-4) and to the positive terminal of the DC battery. The negative of a DC battery is connected to the negative bus of breadboard (6). Set function generator to 6V rms and supply the circuit. For analog function generator, you can measure its output voltage using voltmeter set to AC mode or just by using oscilloscope with the peak voltage equal to $6*\sqrt{2}$ (8.484V). Set channel one and channel two (CH1 and CH2) of oscilloscope to 5Volt/div and to 10mSec/div vertical sensitivity and horizontal sensitivity respectively.

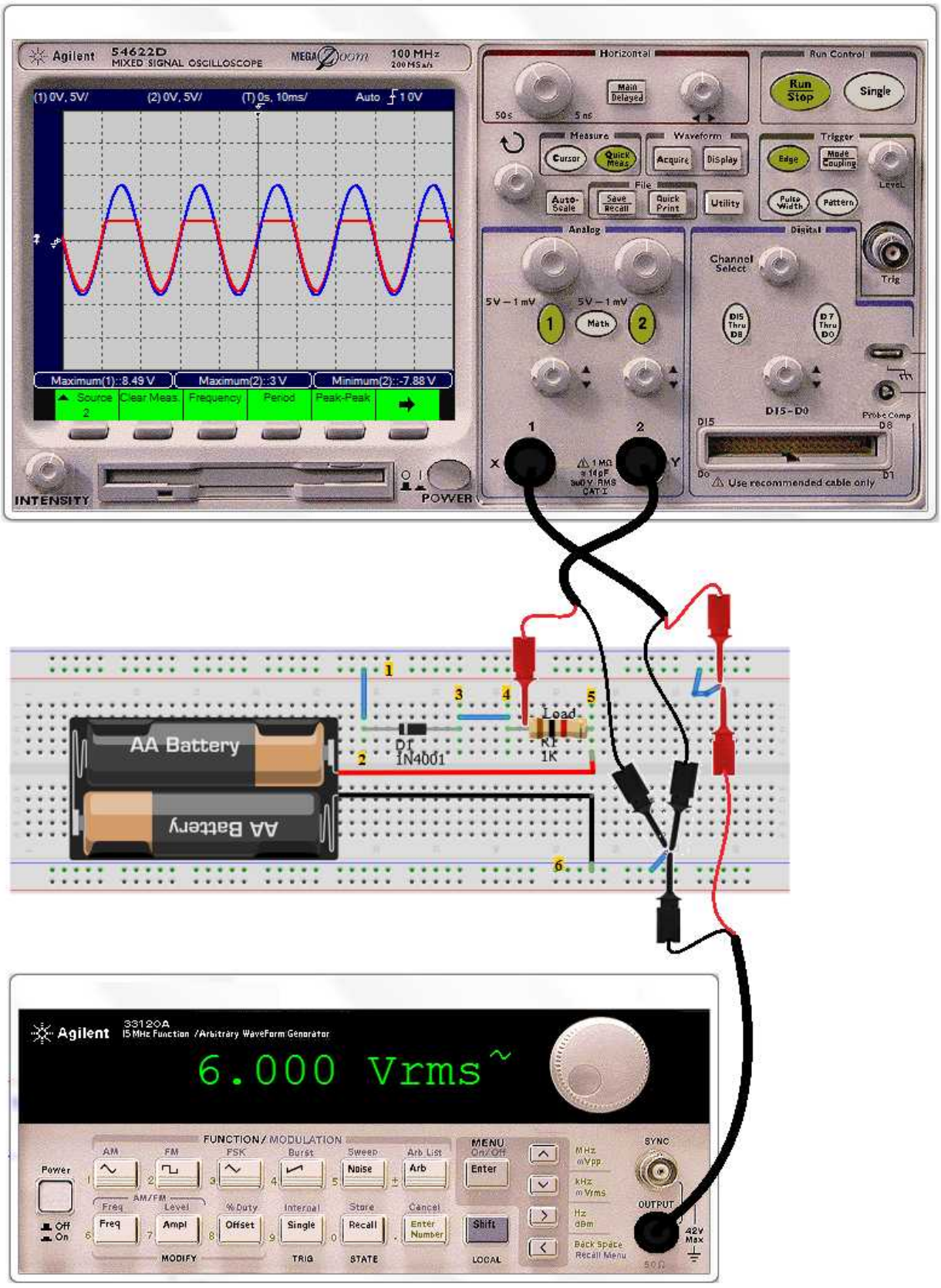


Figure 8-4: Series positive clipper with positive bias, real world circuit connection

You can adjust vertical sensitivity and horizontal sensitivity to make the wave take up most of the screen without chopping any of its amplitude off and in the easy way reading and calculation. The output voltage is taken between the terminal end of the load resistor and the battery. The oscilloscope should be AC coupled to read the input waveform but should be DC coupled to read the output waveform.

The oscilloscope display may have a natural coarseness, which can be reduced by selecting the Average function. Try to use as few samples as possible to avoid long delays while moving from one display to another.

Push the AUTOSCALE button to display both channels. Reposition so that the 0V is at the midline on the both channels and the waveforms appear to overlap.

At very high frequencies AUTOSCALE may not work because the filtered signal is too small. Use manual adjustments of the volts/division to reveal the signal. At least one full period of the waveform must be in view to for the oscilloscope measure functions to be accurate.

The input AC voltage waveform is displayed from channel one (CH1) of oscilloscope while the channel two (CH2) is showing the clipped wave. As result shown from oscilloscope, the maximum input voltage is 8.49V, the maximum output voltage is 3V and the minimum output voltage peak value is –7.88V.

Since a positive portion of the input wave exceeding +3V is removed or clipped out, the circuit is called series positive clipper with positive bias. The clipped level can be shifted up by varying the bias voltage.

- **Series Positive Clipper with Negative Bias**

A series positive clipper with negative bias, the negative terminal of the battery is connected to the anode of diode through a load resistor as shown in circuit example figure 8-5.

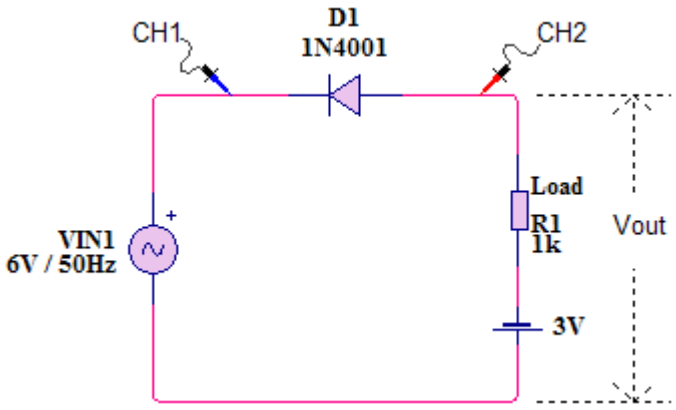


Figure 8-5: Circuit for series positive clipper with negative bias

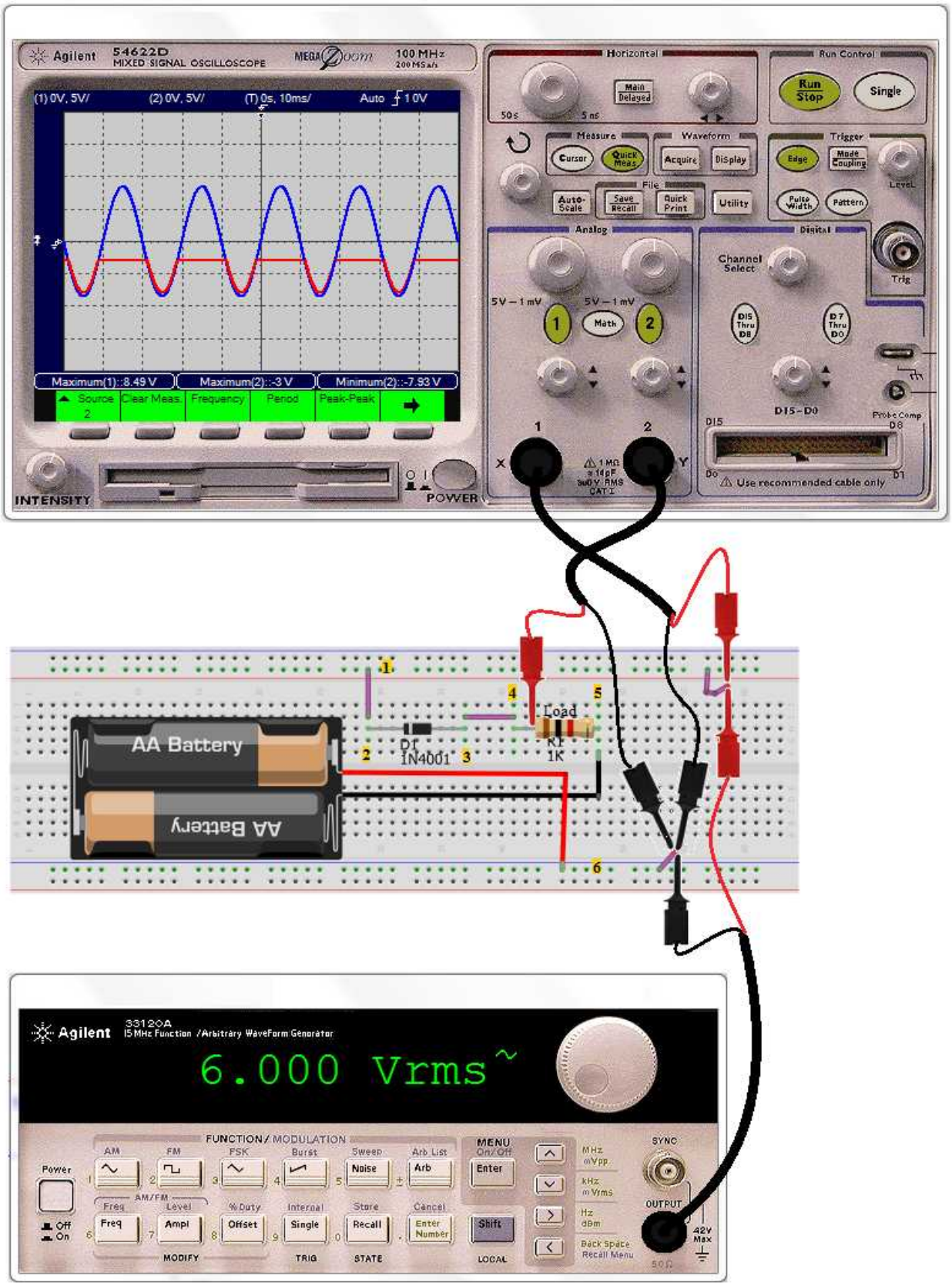


Figure 8-6: Series positive clipper with negative bias, real world circuit connection

Procedure

Connect the circuit as shown in figure 8-6. The input AC supply from function generator is plugged on power bus and ground bus (1-6) of breadboard. The red lead to positive bus of breadboard and black lead to negative bus. Normally the red lead from a function generator is sometimes called signal while the black is taken as ground but for a transformer the polarity does not matter. Therefore the red probe has to be connected to a positive bus of breadboard(1) and black probe to a negative bus of breadboard (6). Cathode of diode is connected to a positive power bus through a jumper wire (1-2). A load resistor is connected to the anode of diode (3-4) and to a negative terminal of the DC battery. The positive of a DC battery is connected to the negative bus of breadboard (6).

Set function generator to generate 6V rms sinusoidal and supply the circuit. For analog function generator, you can measure its output voltage using voltmeter set to AC mode or just by using oscilloscope with the peak voltage equal to $6*\sqrt{2}$ (8.484V). Set channel one and channel two (CH1 and CH2) of oscilloscope to 5Volt/div and to 10mSec/div vertical sensitivity and horizontal sensitivity respectively. The oscilloscope should be AC coupled to read the input waveform but should be DC coupled to read the output waveform.

You can adjust vertical sensitivity and horizontal sensitivity to make the wave take up most of the screen without chopping any of its amplitude off and in the easy way reading and calculation. The output voltage is taken between the terminal end of the load resistor and the battery.

The input AC voltage waveform is displayed from channel one (CH1) of oscilloscope while the channel two (CH2) is showing the clipped wave. As result shown from oscilloscope, the maximum input voltage is 8.49V, the maximum output voltage is –3V and the minimum output voltage peak value is –7.93V. A portion of the input wave exceeding –3V is removed or clipped, the circuit is called series positive clipper with negative bias.

The clipping level can be shifted down the X-axis by varying the bias voltage but not exceed the input AC supply level.

As inspected, being either unbiased or biased positive clipper, a removed portion of the wave takes place during the positive cycle only and when the AC input voltage is greater than battery voltage.

8. 1. 3. Series negative clipper

In a series negative clipper a diode is connected in a direction appositive to that of a positive clipper. A series negative clipper the diode is connected in series with the output load and this removes or clips wholly the negative half of the input. The role of diode in such clipper is to operate as a series switch between the source and load.

Experiment 8-3. Series negative clipper

Build a series negative clipper containing diode, a resistor which stands for a load, and supply the circuit with 6VAC. Display the resulting on oscilloscope. The part list is given below.

Part lists

No	Items	Specifications	Quantity
1	Oscilloscope	Agile oscilloscope 54622D	1
2	6VAC supply	Agilent function generator 33120A	1
3	Resistors	5.6KΩ	1
4	Breadboard	Prototyping board (RSR 03MB102)	1
5	Connecting wire	22-gauge (0.33mm^2)solid wire	20cm
6	Diode	1N4002	1

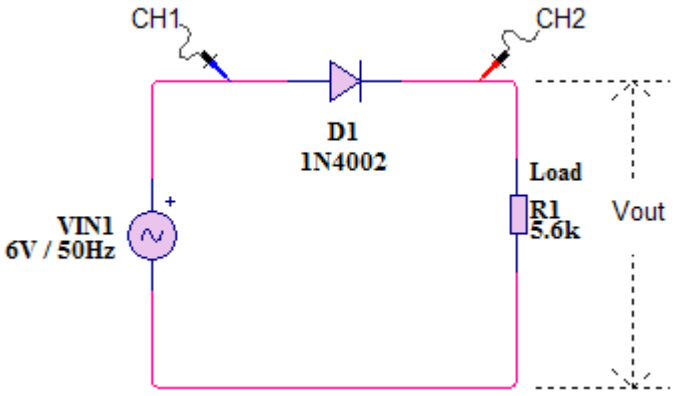


Figure 8-7: Series negative clipper circuit

Working Principle of the Circuit

During the positive half cycle of the input AC voltage, the anode of diode is positive with respect to the cathode. Therefore, the diode is forward biased and it acts as a closed switch as a result, all the input voltage appears across the load.

During the negative half cycle of the input voltage, the anode is negative with respect to the cathode. Therefore the diode is reverse biased and it acts as an open switch, thus there is no voltage drop across the resistor during the negative half cycle as shown in the output waveform on oscilloscope.

Procedure

Connect the circuit as illustrated in figure 8-8. The AC supply from a function generator is connected to power bus and ground bus (1-6) of breadboard. The red lead from a function generator is connected to a positive bus of breadboard(1) and black probe to a negative bus of breadboard (6). Anode of diode is connected to a positive power bus through a jumper wire (1-2). A load resistor is connected to the cathode of diode (3-4) and to the ground or negative power bus through a jumper wire (5-6). Set function generator to 6V rms or 6*√2 (8.48V) peak value. Measure the rms value from a function generator by using voltmeter set in VAC mode or use the oscilloscope to measure the peak value.

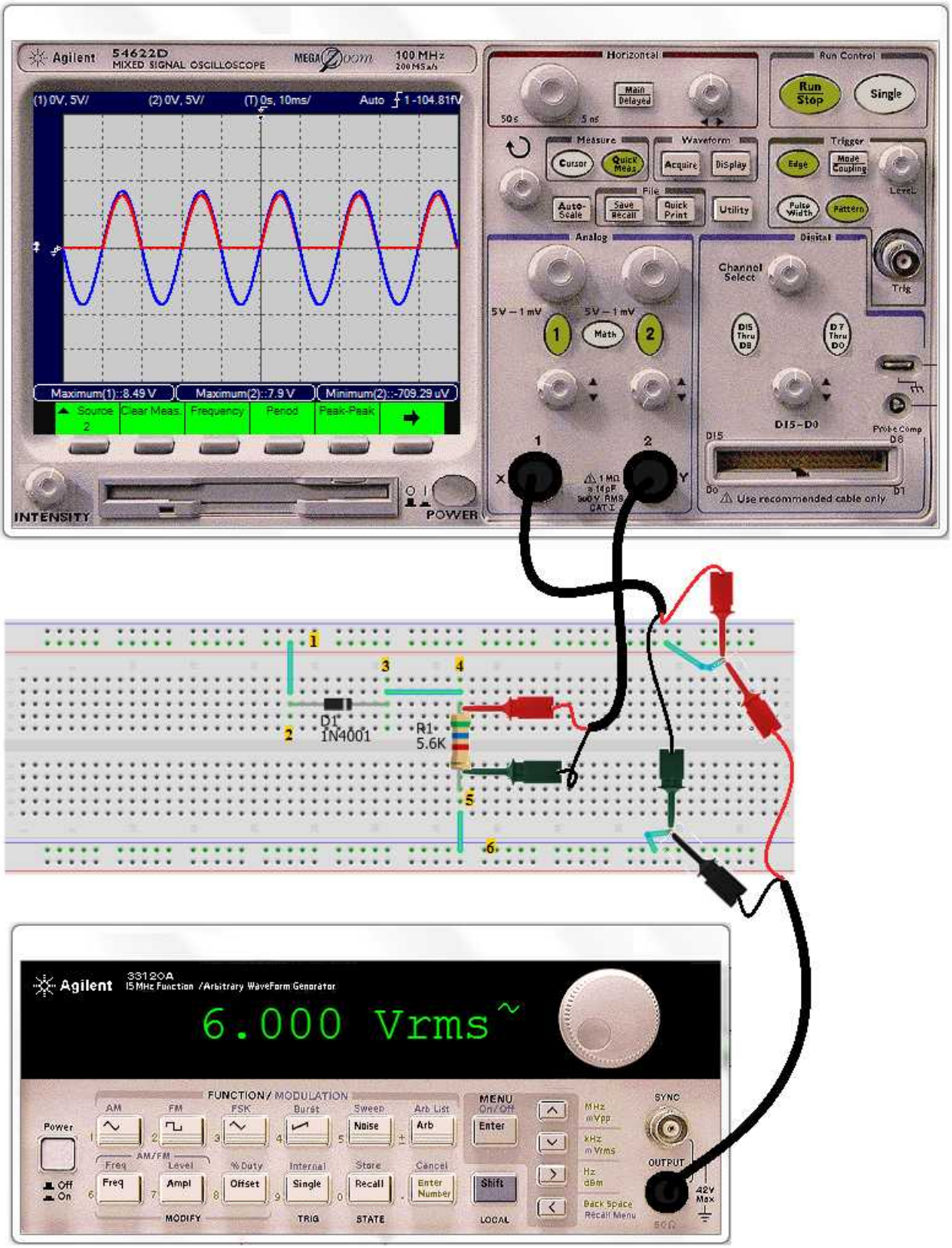


Figure 8-8: Series negative clipper, real world circuit connection

Set channel one and channel two (CH1 and CH2) of oscilloscope to 5Volt/div and to 10mSec/div vertical sensitivity and horizontal sensitivity respectively. You can adjust vertical sensitivity and horizontal sensitivity to make the wave take up most of the screen without chopping any of its amplitude off and in the easy way reading and calculation.

Push the AUTOSCALE button to display both channels. Reposition so that the 0V is at the mid-line on the both channels and the waveforms appear to overlap. The oscilloscope display may have a natural coarseness, which can be reduced by selecting the Average function.

Try to use as few samples as possible to avoid long delays while moving from one display to another. You can push the AUTOSCALE button to display both channels.

The input AC voltage waveform is displayed from channel one (CH1) of oscilloscope while the channel two (CH2) is showing the clipped wave on the load resistor. As result shown from oscilloscope, the maximum input voltage is 8.49V, the maximum output voltage is 7.9V and the output minimum peak value is –709.29uV or simply say zero volt. Actually a voltmeter measuring voltage ranging in micro displays zero value. However a negative portion of the input wave is removed or clipped completely. Due to this reason the circuit is called series negative clipper.

It may be observed that if it is desired to remove or clip the negative half cycle of the input, the only thing to be done is to reverse the polarities of the diode in the circuit. Such a clipper is then called a series negative clipper

8. 1. 4. Series-negative clipper with bias

When it requires removing a small portion of negative half cycle of the input AC signal to prevent it from exceeding a specific amplitude level a DC supply is inserted in a circuit and this specifies which level the wave is to be clipped. Depending on the orientation of the battery, a circuit can either be a series negative clipper with a positive bias or a series negative clipper with a negative bias.

Experiment 8-4. Series negative clipper with bias

For series negative clipper with bias, the clipping take place during the negative half cycle only when the AC input voltage is greater than biasing voltage. The clipping level can be shifted up or down by changing the orientation of the battery or by varying the bias voltage. The effect of bias DC source is that even if there may be no input AC voltage, the output will remain the voltage of the DC source. This means that the output voltage will be limited to the biasing voltage on the side of clipping.

- **Series Negative Clipper with Positive Bias**

Build a circuit on breadboard having a diode connected in series with a combination of a battery and a resistor and supply it with 6VAC sinusoidal. The cathode of diode is connected to the positive of the battery. Detailed items for such circuit are given in the list below.

Part lists

No	Items	Specifications	Quantity
1	Oscilloscope	Agile oscilloscope 54622D	1

2	6VAC supply	Agilent function generator 33120A	1
3	Resistors	5.6KΩ	1
4	Breadboard	Prototyping board (RSR 03MB102)	1
5	Connecting wire	22-gauge (0.33mm^2)solid wire	30cm
6	Diode	1N4001	1
7	1.5VDC supply	1.5V cell battery	1

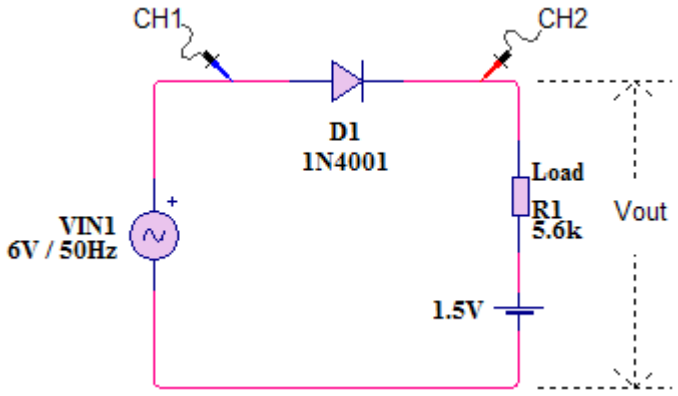


Figure 8-9: Circuit for series negative clipper with positive bias

Procedure

Connect the circuit as illustrated in figure 8-10. The AC supply from function generator is plugged on power bus and ground bus (1-6) of breadboard. The red lead to the positive bus of breadboard and black probe to a negative bus. The red probe is connected to a positive bus of breadboard (1) and black probe to a negative bus of breadboard (6). The anode of diode is connected to a positive power bus through a jumper wire (1-2). A load resistor is connected to the cathode of diode (3-4) and to a positive terminal of the AA cell battery (5). The negative of the AA cell battery is connected to negative bus on breadboard (6).

After connecting the circuit on breadboard, set function generator to 6V rms sinusoidal and supply the circuit. For analog function generator, you can measure its output voltage using voltmeter set to AC mode or just by using oscilloscope with the maximum voltage equal to 8.484V.

Set channel one and channel two (CH1 and CH2) of oscilloscope to 5Volt/div and to 10mSec/div vertical sensitivity and horizontal sensitivity respectively. You can adjust vertical sensitivity and horizontal sensitivity to make the wave take up most of the screen without chopping any of its amplitude off and in the easy way reading and calculation.

The oscilloscope display may have a natural coarseness, which can be reduced by selecting the Average function. Try to use as few samples as possible to avoid long delays while moving from one display to another. Push the AUTOSCALE button to display both channels. Reposition so that the 0V is at the midline on the both channels and the waveforms appear to overlap. The output voltage is taken between the terminal end of the load resistor and the negative terminal of AA cell battery.

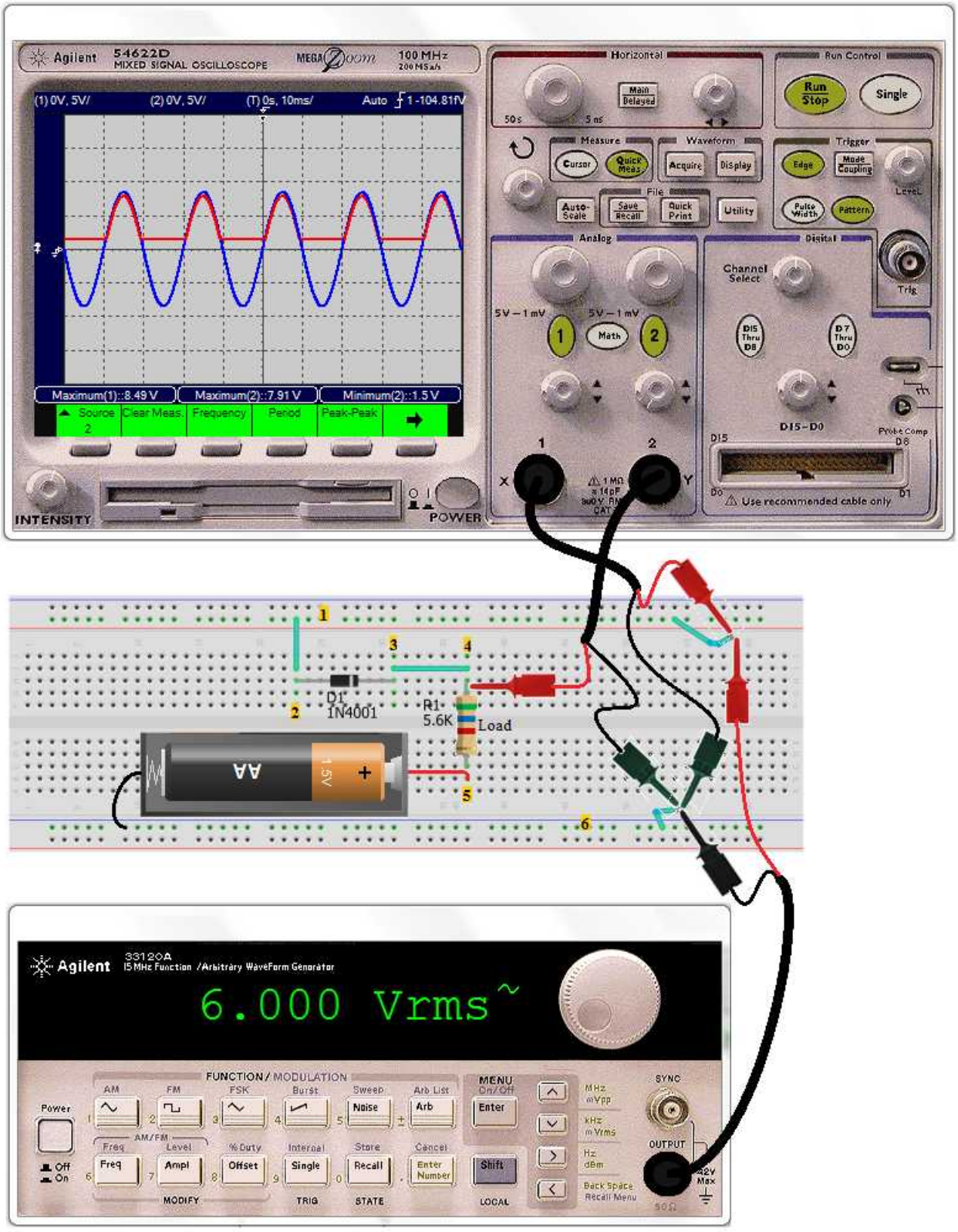


Figure 8-10: Series negative clipper with positive bias, real world circuit connection

The input AC voltage waveform is displayed from channel one (CH1) of oscilloscope while the channel two (CH2) is showing the clipped wave. As result shown from oscilloscope, the maximum input voltage is 8.49V, the maximum output voltage is 7.91V and the minimum output voltage peak value is 1.5V. A portion of the input wave less than 1.5V is removed or clipped, the circuit is called series negative clipper with positive bias. This level can be modified by using variable DC power supply in the way that the voltage of the battery does not exceed that of the AC supply.

- **Series Negative Clipper with Negative Bias**

In a series negative clipper with a negative bias the battery is connected in a direction apposite to that of a negative clipper with positive bias. The negative terminal of the battery is connected to the cathode of diode as shown in figure 8-11.

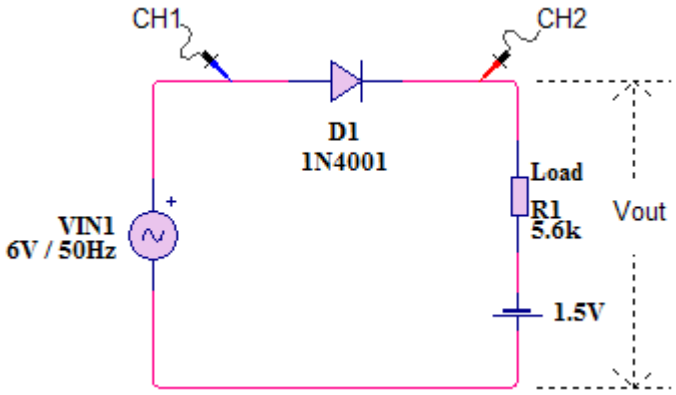


Figure 8-11: Circuit for series negative clipper with negative bias

Procedure

Connect the circuit as shown in arrangement on breadboard figure 8-12. Connect the AC supply from function generator to a power bus and ground bus (1-6) of breadboard. The red lead from a function generator is connected to a positive bus of breadboard (1) and black lead to a negative bus (6). The anode of diode is connected to a positive power bus through a jumper wire (1-2). A load resistor is connected to the cathode of diode (3-4) and to a negative terminal of the AA cell battery (5). The positive of the AA cell battery is connected to negative bus on breadboard (6).

After connecting the circuit on breadboard, supply the circuit with 6V rms sinusoidal from a function generator. Set channel one and channel two (CH1 and CH2) of oscilloscope to 5Volt/div and to 10mSec/div vertical sensitivity and horizontal sensitivity respectively.

The oscilloscope should be AC coupled to read the input waveform but should be DC coupled to read the output waveform.

Adjust vertical sensitivity and horizontal sensitivity to make the wave take up most of the screen without chopping any of its amplitude off and in the easy way reading and calculation. The output voltage is taken between the terminal end of the load resistor and the positive terminal of AA cell battery.

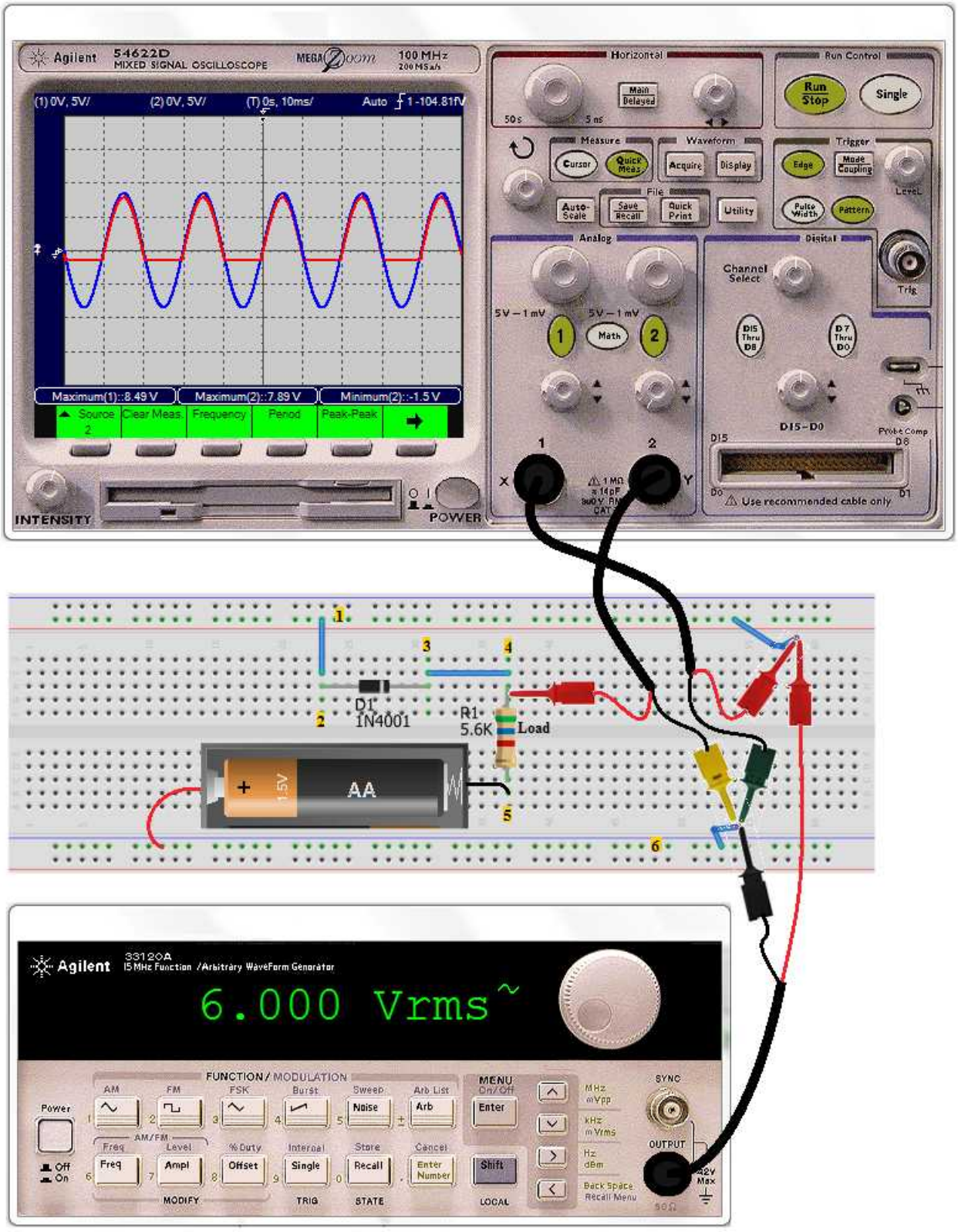


Figure 8-12: Series negative clipper with negative bias, real world circuit connection

The input AC voltage waveform is displayed from channel one (CH1) of oscilloscope while the channel two (CH2) is showing the clipped wave. As result shown from oscilloscope, the maximum input voltage is 8.49V, the maximum output voltage is 7.91V and the minimum output voltage peak value is –1.5V. A portion of the input wave less than –1.5V is removed or clipped, the circuit is called series negative clipper with negative bias. This level can be modified by using variable DC power supply in the way that the voltage of the battery does not exceed that of the AC supply.

8. 2. Shunt or parallel clipper

A parallel clipper circuit uses a resistor connected in series with the input AC signal and the output signal is developed across the diode. The output is in parallel with the diode hence the circuit name *parallel clipper*. The parallel clipper can limit either the positive or negative alternation of the input signal to a specific level. In a clipper circuit, the diode acts as a switch. The diode acts as a closed switch when is forwarded biased, and the input AC voltage is greater than zero diode voltage drop (0.7V) and as an open switch when is reverse biased. There are many forms of parallel clipper circuits depending on diode position, and biasing DC voltage. The output waveform has the same shape as that of a series clipper but for parallel clipper the diode voltage drop is taken in account as the output is in parallel with diode.

8. 2. 1. Shunt (parallel) positive clipper

In the parallel Positive clippers the alp will develop when the diode is cut off. For positive half wave of AC input voltage, the diode is forward biased and the output voltage is limited to diode voltage drop, 0.7V. At the negative half cycle of the input AC voltage, the diode is reverse biased and acts as an open switch, therefore, the output voltage looks like the input voltage.

Experiment 8-5. Shunt (parallel) positive clipper

Build a circuit having a series resistor and the diode in such way that the output is taken to the parallel terminal of the diode. The output is developed at negative half cycle of the input AC voltage while during positive half cycle the output is clipped off to the diode volatge drop.

Part list

No	Items	Specifications	Quantity
1	Oscilloscope	Agile oscilloscope 54622D	1
2	3VAC supply	Agilent function generator 33120A	1
3	Resistors	68Ω, 1/2watt	1
4	Resistors	1KΩ, 1/4watt	1
5	Breadboard	Prototyping board (RSR 03MB102)	1
6	Connecting wire	22-gauge (0.33mm^2)solid wire	40cm
7	Diode	1N4001	1

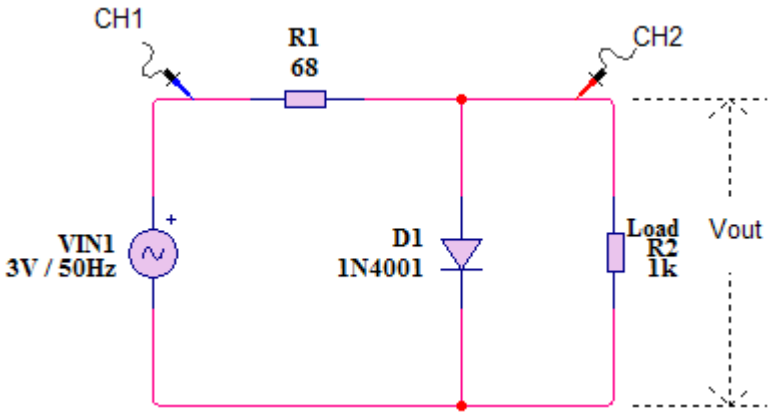


Figure 8-13: Shunt (parallel) positive clipper circuit

Parallel clippers are operated from AC supply with a series resistor, R_1 used to limit the current to a safe value flowing through a diode.

For a positive half wave of the input AC voltage V_{in}, the diode D_1 is forward biased and the voltage to the terminal of the load resistor R_2 is equal to the diode voltage drop, that is 07V. For a negative half wave, the diode D_1 is reverse biased and behaves like an open switch and the most of the input voltage develops across the load resistor R_2 despite the voltage drop on series resistor R_1. This can be calculated using Ohm's law.

$V_{Load} = V_{in} [R_{Load}/(R_s+R_{Load})] = 3V[1K\Omega/(68\Omega+1K\Omega)] = 2.81V$

The minimum value is given by : $V_{rms} * \sqrt{2} = 2.8V * 1.414$

$= 3.97V$ (with a negative sign $-3.97V$)

chap 8

Procedure

Connect the circuit as illustrated in figure 8-14. Connect the AC supply from function generator to a power bus and ground bus (1-7) of breadboard. The red lead from a function generator is connected to a positive bus of breadboard (1) and black lead to a negative bus (7). The series resistor Rs1 is connected to a positive power bus through a jumper wire (1-2) and to the anode of diode (3). The cathode of diode is connected to a negative power bus of breadboad through a jumper wire (4-7). A load resistor is connected to the anode of diode (3-5) and to a negative bus of breadboad through a jumper wire (6-7). The circuit is supplied with 3V rms sinusoidal from a function generator. The channel one of oscilloscope is at 2Volt/div vertical sensitivity while the channel two (CH2) is at 5Volt/div vertical sensitivity.

The horizontal sensitivity is set to 10mSec/div. Whenever nedded, adjust vertical sensitivity and horizontal sensitivity to make the wave take up most of the screen without chopping any of its amplitude and in the easy way reading and calculation. The output voltage is taken on the terminal of the diode.

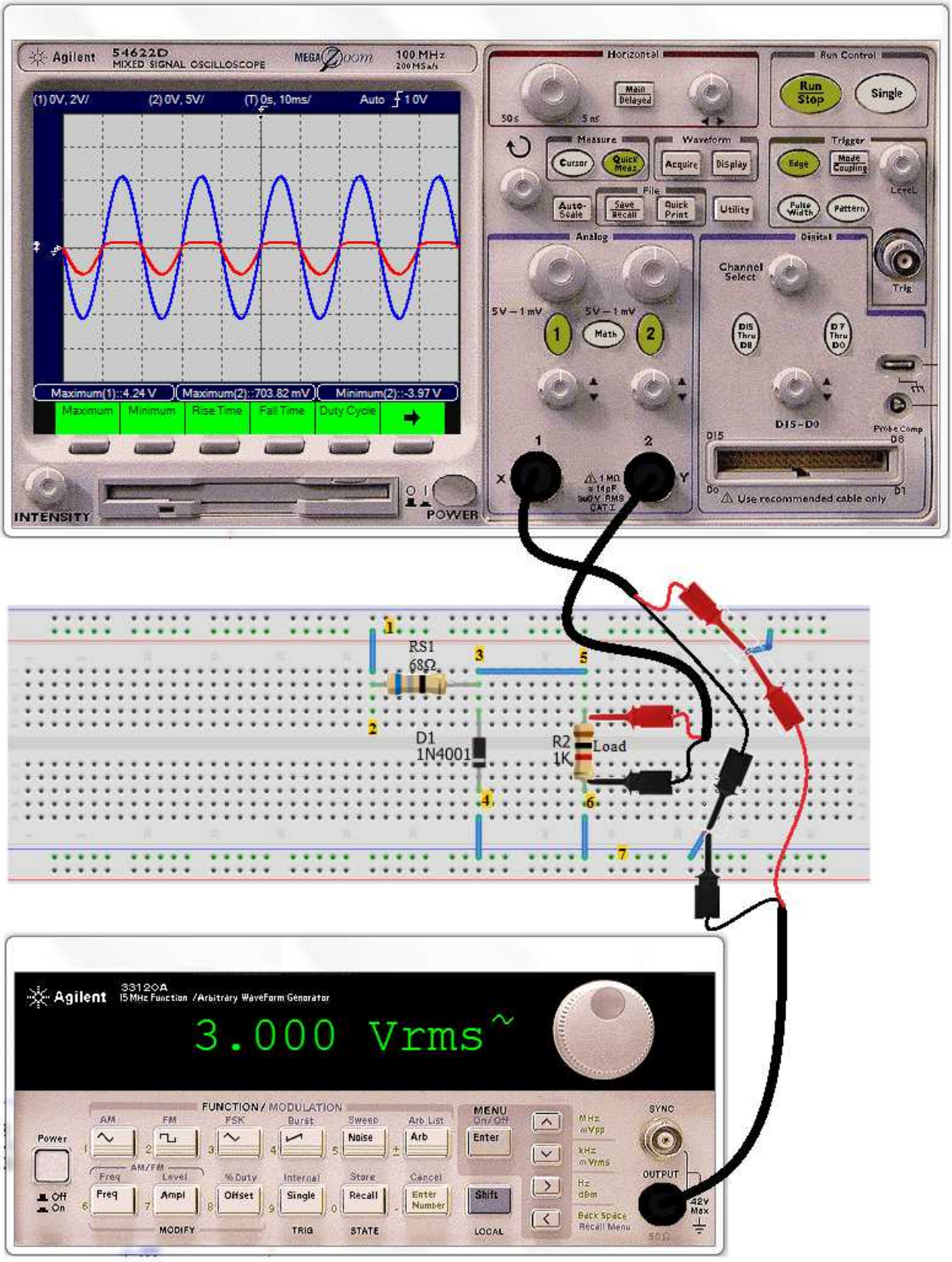


Figure 8-14: Shunt (parallel) positive clipper, real world circuit connection

The input AC voltage waveform is displayed from channel one (CH1) of oscilloscope and the channel two (CH2) displays the resulting clipped wave. As result shown from oscilloscope, the maximum input voltage is 4.42V, the maximum output voltage is 703.82mV and the minimum output voltage peak value is –3.97V.

8. 2. 2. Shunt or parallel positive clipper with bias

When the necessity to limit the positive half wave of the input AC signal to a desired level oither than 0.7V is a must, a DC voltage for biasing is inserted in series with a diode. The position of the biasing voltage polarity determines the type of biased shunt clipper.

- **Shunt Positive Clipper with Positive Bias**

Shunt positive clipper with positive bias, positive terminal of the battery is connected to the cathode of the diode. This causes the diode to be reversed biased at all times except when the input AC signal is more positive with respect to the bias voltage (i.e V_{in} greater than $V_{Baterry}$).

Experiment 8-6. Shunt positive clipper with positive bias

Design a shunt positive clipper that limits the positive half cycle to 2.2 V. Use 82 Ω as a series resistor and 1.5 KΩ as load resistor. Measure the resulting output voltage V_{out} using oscilloscope.

Part list

No	Items	Specifications	Quantity
1	Oscilloscope	Agile oscilloscope 54622D	1
2	3VAC supply	Agilent function generator 33120A	1
3	Resistors	82Ω, ½ watt	1
4	Resistors	1.5KΩ, ¼ watt	1
5	Breadboard	Prototyping board (RSR 03MB102)	1
6	Connecting wire	22-gauge solid wire	40cm
7	Diode	1N4005GP	1
8	1.5VDC supply	1.5V AA cell Battery	1

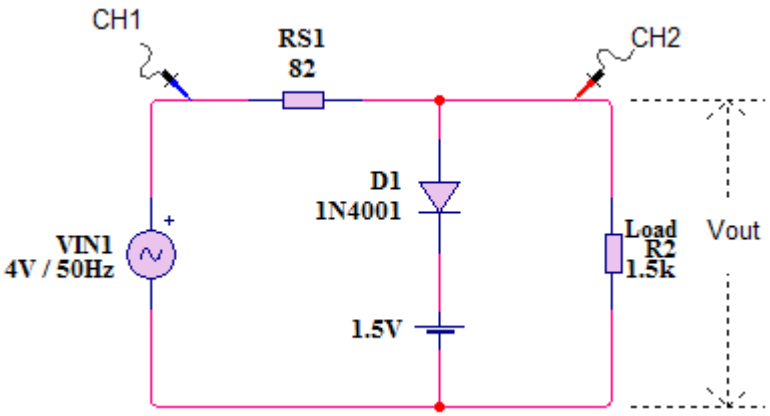


Figure 8-15: Shunt positive clipper with positive bias circuit

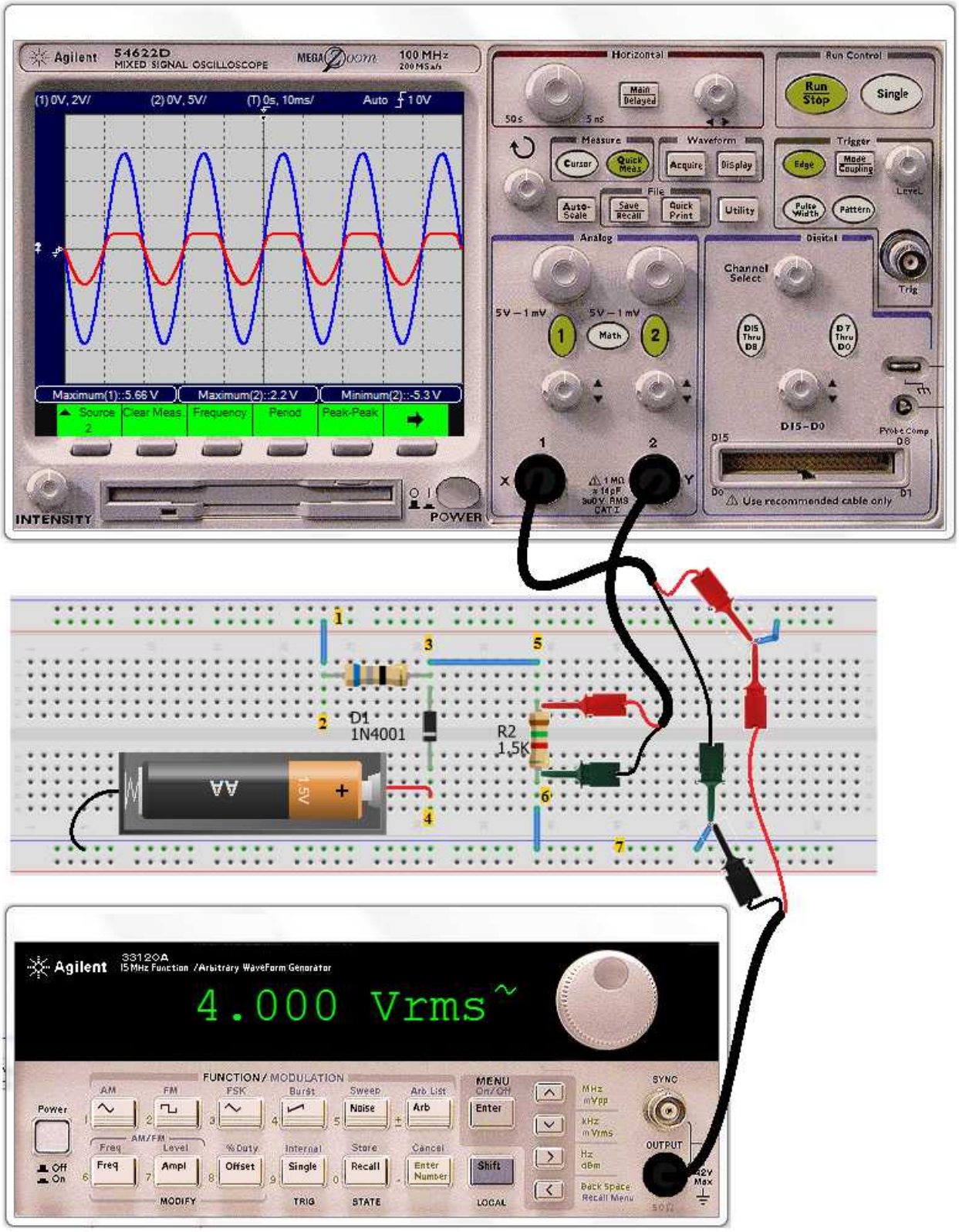


Figure 8-16: Shunt positive clipper with positive bias, real world circuit connection

Working Principle of the Circuit

For the positive half wave of the input AC voltage V_{in} greater than the battery bias voltage (1.5V), the diode D_1 is forward biased and the voltage to the terminal of the load resistor R_2 is equal to the diode voltage drop plus the battery bias voltage (07V+1.5V), that is 2.2V. For a negative half wave, the diode D_1 is reverse biased and behaves like an open switch and the most of the input voltage develops across the load resistor R_2 despite the voltage drop on series resistor R_{S1}. This is given by the equation below.

$$V_{Load} = V_{in} [R_{Load}/(R_s+R_{Load})]$$
$$= 4V [1.5K\Omega/(82\Omega+1.5K\Omega)]$$
$$= 3.79V$$

The minimum value is given by: $V_{rms}*\sqrt{2} = 3.79V*1.414$

$= 5.36V$ (with a negative sign $-5.36V$)

This implies that the output voltage will oscillate between two extremities. i.e 2.2 Volts for maximum positive peak and –5.36 Volts for negative peak. These values can be changed to the desired amplitude values by changing the bias voltage and input supply voltage.

- **Shunt Positive Clipper with Negative Bias**

Shunt positive clipper with negative bias, negative terminal of the battery is connected to the cathode of the diode. This keeps the diode to be in forward bias all along the positive half cycle of the input AC signal. The input signal lying above the battery biasing voltage ($V_{Baterry}$) is clipped.

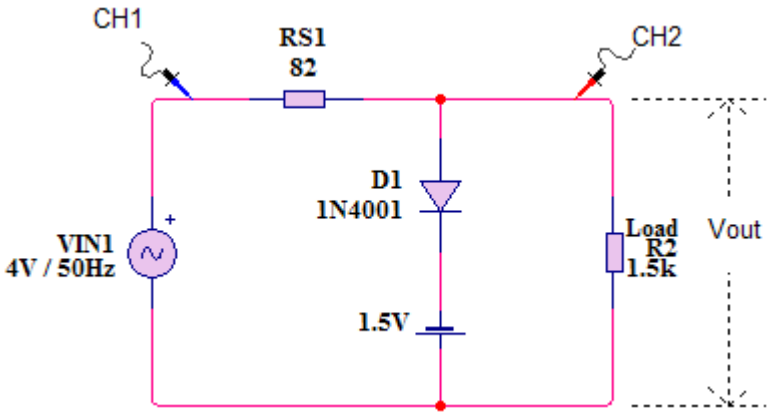


Figure 8-17: Shunt positive clipper with negative bias

Working Principle of the Circuit

For a positive half wave of the input AC voltage V_{in}, the diode D_1 is forward biased. As the cathode of diode is connected to the negative terminal of the biasing battery, the diode remain forwarded biased at voltage less than DC bias (i.e. –1.5V). At this time the voltage to the terminal of the load resistor R_2 is equal to the diode voltage drop minus the battery bias voltage (07V–1.5V), that is –0.8V.

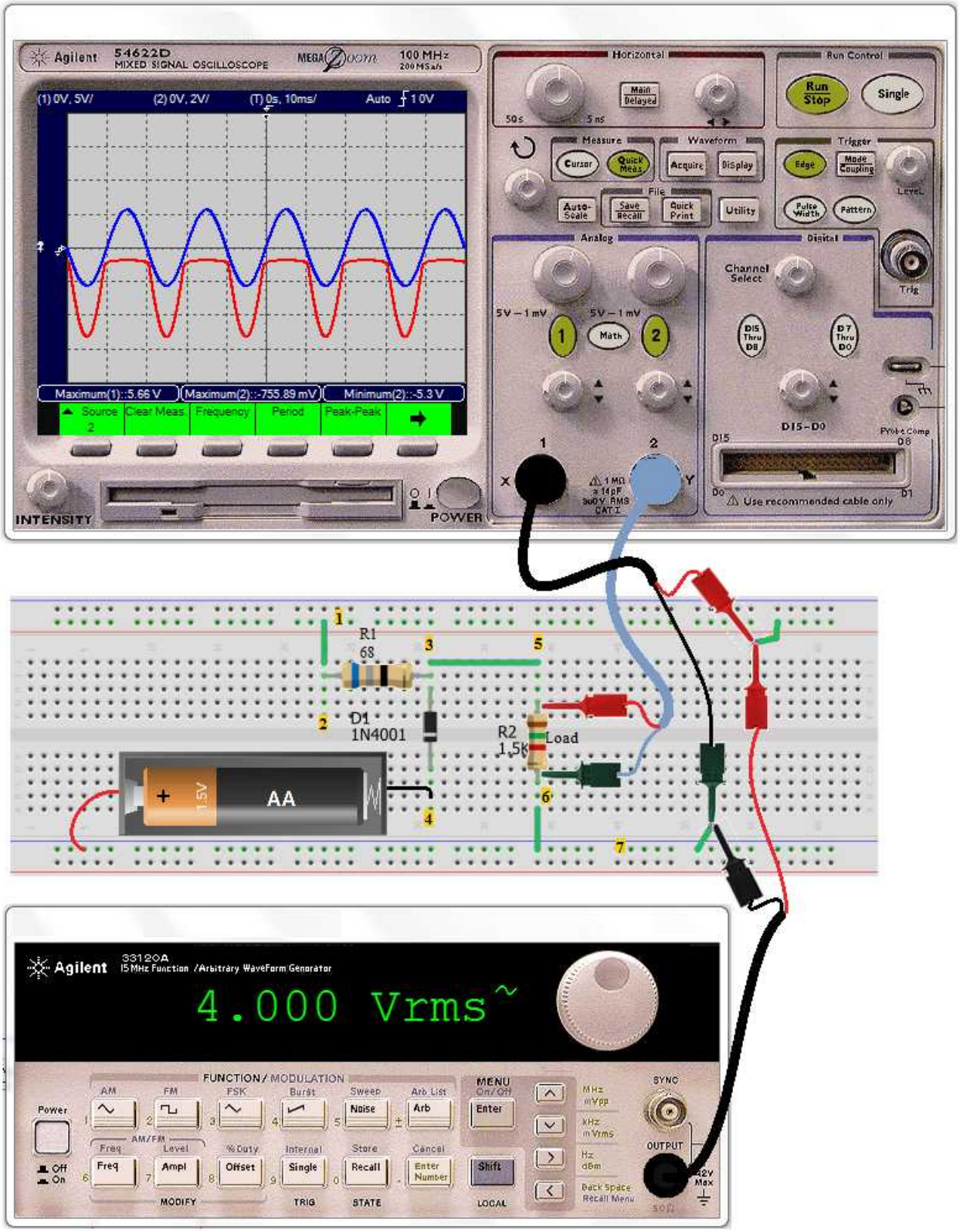


Figure 8-18: Shunt positive clipper with negative bias, real world circuit connection

For a negative half wave, the diode D_1 is reverse biased and behaves like an open switch and the most of the input voltage develops across the load resistor R_2 despite the voltage drop on series resistor R_{S1}. This is given by the equation below.

$$V_{Load} = V_{in} \ [R_{Load}/(R_s+R_{Load})]$$
$$= 4V \ [1.5K\Omega/(82\Omega+1.5K\Omega)]$$
$$= 3.79V$$

The minimum value is given by: $V_{rms}*\sqrt{2} = 3.79V*1.414$

$= 5.36V$ (with a negative sign: $-5.36V$)

This implies that the output voltage will oscillate between two extremities. i.e –0.8 Volts for maximum peak and –5.36 Volts for minimum peak.

These values can be changed to the desired amplitude values by changing the bias voltage and input supply voltage by making sure that the bias voltage is not greater than the ac supply voltage since this can create back effect and destroy the ac supply and also no desired clipping since the diode will stay reversed biased as long as the ac voltage is less than the bias voltage.

8. 2. 3. Shunt or parallel negative clipper

The negative clipper allows to pass the positive half cycle of the input voltage and clipped the negative half cycle. In the parallel negative clippers the alp will be developed when the diode is cut off. For positive half wave of AC input voltage, the diode is reverse biased and acts as an open switch, at the negative half cycle of the input AC voltage, the diode is forward biased and acts as a closed switch.

Experiment 8-7. Shunt (parallel) negative clipper

Build a circuit having a series resistor and the diode in such way that the output is taken to the parallel terminal of the diode. The output is developed at positive half cycle of the input AC voltage while during negative half cycle the output is cut off.

Part list

No	Items	Specifications	Quantity
1	Oscilloscope	Agile oscilloscope 54622D	1
2	3VAC supply	Agilent function generator 33120A	1
3	Resistors	68Ω, 1/2watt	1
4	Resistors	1KΩ, 1/4watt	1
5	Breadboard	Prototyping board (RSR 03MB102)	1
6	Connecting wire	22-gauge ($0.33mm^2$) solid wire	40cm
7	Diode	1N4001	1

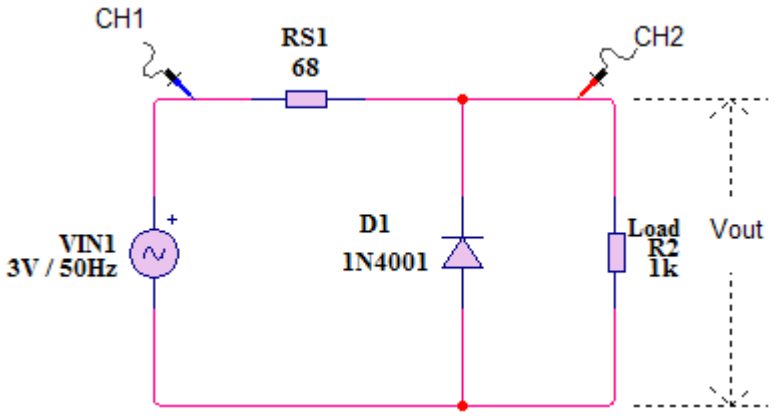


Figure 8-19: Shunt (parallel) negative clipper circuit

Working Principle of the Circuit

In such circuit, figure 8-19, the diode D_1 acts as a closed switch for a negative half wave of the input voltage (i.e. V_{IN} less than zero) and as an open switch for a positive half wave of the input voltage (i.e. V_{in} greater than zero volt). The voltage to the terminal of the load resistor R_2 when diode is forward biased is equal to the diode voltage drop (0.7V). For positive half wave, the diode D_1 is reverse biased and behaves like an open switch and the most of the input voltage develops across the load resistor R_2 despite the voltage drop on series resistor R_{S1}. This can be calculated using Ohm's law.

$$V_{Load} = V_{in} \ [R_{Load}/(R_s+R_{Load})]$$
$$= 3V \ [1K\Omega/(68\Omega+1K\Omega) = 2.81V$$

The maximum value is given by: $Vrms*\sqrt{2} = 2.8V*1.414 = 3.97V$

Procedure

Connect the circuit as illustrated in figure 8-20 . Connect the AC supply from function generator to power bus and ground bus (1-7) of breadboard. The red lead from a function generator is connected to a positive bus of breadboard (1) and black lead to a negative bus (7).

The series resistor R_{s1} is connected to a positive power bus through a jumper wire (1-2) and to the cathode of diode (3). The anode of diode is connected to a negative power bus of breadboad through a jumper wire (4-7).

A load resistor is connected to the anode of diode (3-5) and to a negative bus of breadboad through a jumper wire (6-7). The circuit is supplied with 3V rms sinusoidal from a function generator. The channel one of oscilloscope is at 2Volt/div vertical sensitivity while the channel two (CH2) is at 5Volt/div vertical sensitivity.

The horizontal sensitivity is set to 10mSec/div. Whenever nedded, adjust vertical sensitivity and horizontal sensitivity to make the wave take up most of the screen without chopping any of its amplitude off and in the easy way reading and calculation.

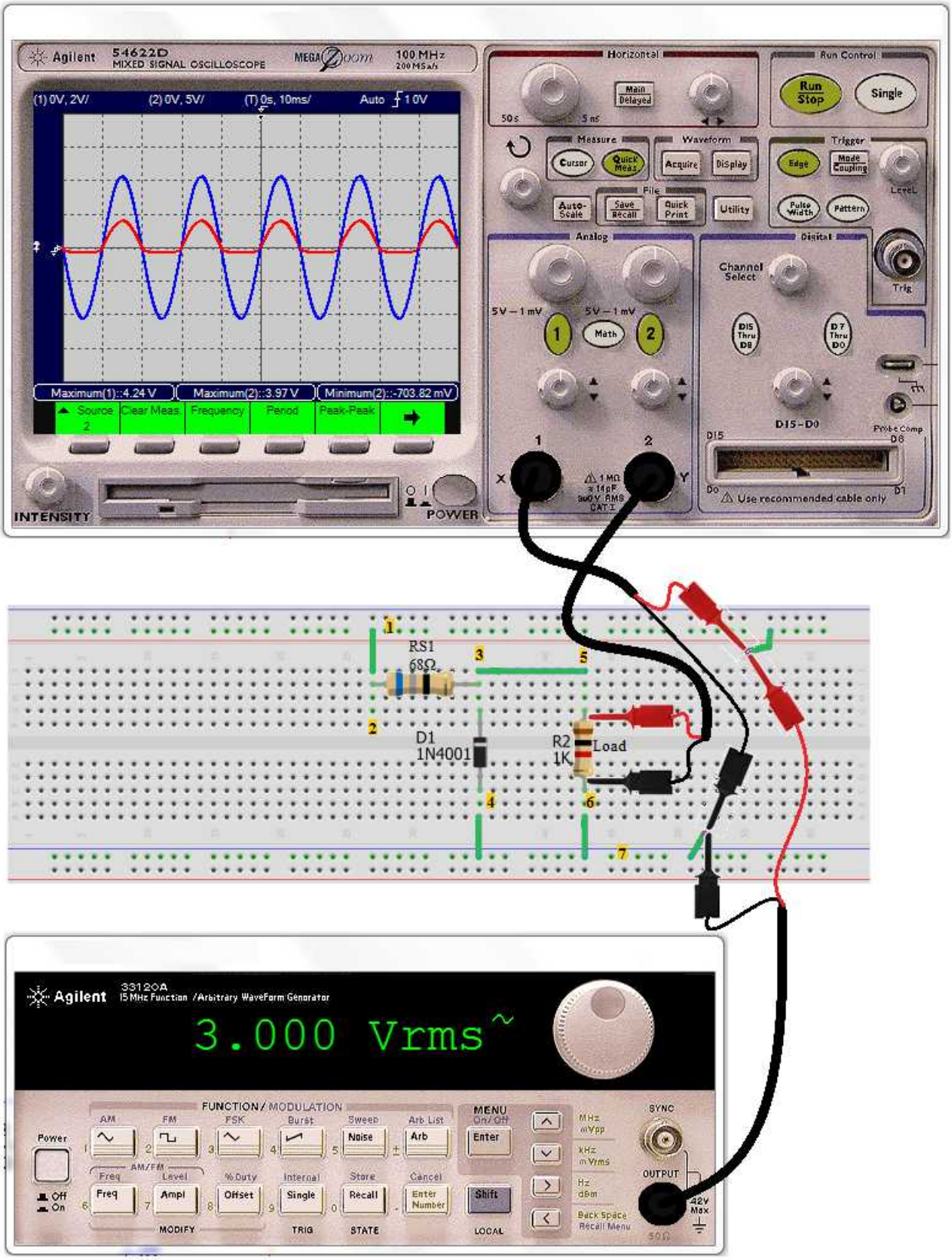


Figure 8-20: Shunt (parallel) negative clipper, real world circuit connection

The oscilloscope display may have a natural coarseness, which can be reduced by selecting the Average function. Try to use as few samples as possible to avoid long delays while moving from one display to another.

The output voltage is taken on the terminal of the diode.

Load resistor R_2 stand for any no -specific electrical device and may just be a kind of shorthand representation of something else more practical than a resistor.

Push the AUTOSCALE button to display both channels. Reposition so that the 0V is at the mid-line on the both channels and the waveforms appear to overlap.

At high frequencies, the amplitude of the signal may be too small to be detected by the Auto-scale feature. You may need to set the Volts/division and time/division scale manually in order to see the signal.

Also, at very high frequencies AUTOSCALE may not work because the signal is too small. Use manual adjustments of the volts/division and time/division to reveal the signal.

The input AC voltage waveform is displayed from channel one (CH1) of oscilloscope and the channel two (CH2) displays the resulting clipped wave.

Press the MEASURE button to determine the voltage peak amplitudes for both channels, and make a record.

As result shown from oscilloscope, the maximum input voltage is 4.42V, the maximum output voltage is 3.97V and the minimum output voltage peak value is –703.82mV. Compare with what you would expect for this circuit based on theoretical calculations.

8. 2. 4. Shunt or parallel negative clipper with bias

It happens that a signal can have negative amplitude larger than the positive half wave. The exceeding peak can be removed and fixed at a desired level by using clipper circuit with bias. This is achieved by inserting a DC voltage in series with a diode and the output is taken to the terminal combination of diode and the battery bias. The negative wave clipped level can be shifted by varying and changing the polarity of the DC voltage.

- **Shunt Negative Clipper with Positive Bias**

In shunt negative clipper with positive bias circuit the clipping take place during the negative half cycle only when the input voltage (V_{in} is less than V_{bias}) and the clipping level can be shifted up or down by varying the biasing DC voltage. In such circuit, the positive terminal of the battery is connected to the anode of the diode. This keeps the diode to be in forward bias all along the negative half cycle of the input AC signal. The input signal lying below the battery biasing voltage ($V_{Baterry}$) is clipped off.

Experiment 8-8. Shunt negative clipper with positive bias

Design a circuit based on shunt negative clipper which allows passing the positive half cycle and clips off the negative to +2.3V close. Supply the circuit with 6VAC and display the resulting wave forms on oscilloscope. Use 270Ω series resistor and 5.6KΩ as Load.

Part list

No	Items	Specifications	Quantity
1	Oscilloscope	Agile oscilloscope 54622D	1
2	9VAC supply	Agilent function generator 33120A	1
3	Resistors	270Ω, 1/2watt	1
4	Resistors	5.6KΩ, 1/2watt	1
5	Breadboard	Prototyping board (RSR 03MB102)	1
6	Connecting wire	22-gauge (0.33mm^2)solid wire	50cm
7	Diode	1N4001	1
8	3VDC supply	1.5V AA cell battery (2)	1

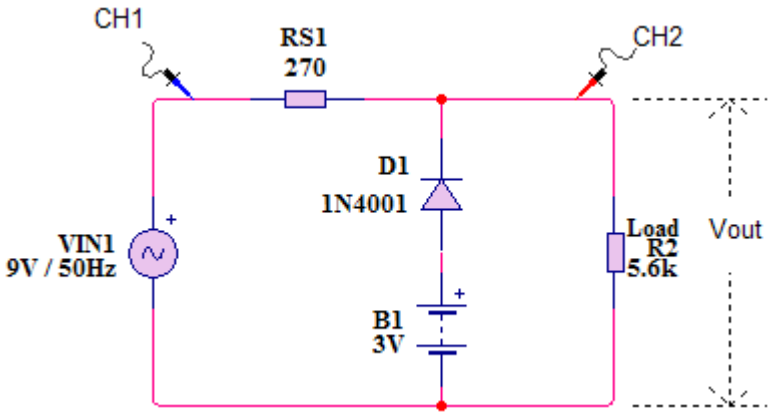


Figure 8-21: Circuit for shunt negative clipper with positive bias

Working Principle of the Circuit

Initially the positive terminal of the battery B_1 forward biases the diode D_1. The diode remains forwarded biased at voltage less than DC bias minus diode voltage drop (i.e. 3V–0.7V). For incoming positive half wave of the input AC voltage V_{in} greater than biasing voltage, the diode D_1 gets reversed biased and diverts it to a load resistor R_2. At this time, the most of the input voltage develops across the load resistor R_2 notwithstanding the voltage drop on series resistor R_{S1}. This is given by the equation below.

$$V_{Load} = V_{in} \ [R_{Load}/(R_s + R_{Load})]$$
$$= 6V \ [5.6K\Omega/(270\Omega + 5.6K\Omega)] = 5.72V$$

The maximum voltage is given by: $V_{rms} * \sqrt{2} = 5.72V * 1.414 = 8.09V$

For a negative half cycle, the diode D_1 stays forwarded biased and the minimum voltage on load resistor R_2 is equal to the battery bias voltage minus the diode voltage drop (3V–0.7V); that is 2.3V.

Procedure

Connect the circuit as illustrated in figure 8-22. Connect the AC supply from function generator to power bus and ground bus (1-7) of breadboard. The red lead from a function generator is connected to a positive bus of breadboard (1) and black lead to the negative bus (7). The series resistor R_{S1} is connected to a power bus through a jumper wire (1-2) and to the cathode of diode D_1 (3). The positive of the battery is connected to the anode of diode (4) and its negative terminal is connected to the negative bus of the breadboard. The load resistor is connected to the cathode of diode (3-4) and to the negative power bus of breadboard (7). The circuit is supplied with 6V rms sinusoidal from a function generator. Channel one (CH1) is at 10Volt/div and channel two at 5Volt/div vertical sensitivity and horizontal sensitivity is at 10mSec/div.

Adjust vertical sensitivity and horizontal sensitivity to make the wave take up most of the screen without chopping any of its amplitude off and in the easy way reading and calculation. The oscilloscope display may have a natural coarseness, which can be reduced by selecting the Average function. Try to use as few samples as possible to avoid long delays while moving from one display to another.

At least one full period of the waveform must be in view for the oscilloscope measure functions to be accurate.

Push the AUTOSCALE button to display both channels. Reposition so that the 0 V is at the midline on the both channels and the waveforms appear to overlap. The output voltage is taken between the cathode of diode and the negative terminal of the battery.

The channel one (CH1) of oscilloscope is displaying the input AC voltage waveform while the channel two (CH2) is displaying the resulting output voltage. The oscilloscope should be AC coupled to read the input waveform but should be DC coupled to read the output waveform.

Press the MEASURE button to determine the voltage RMS amplitudes for both channels, and make a record. As result shown from oscilloscope, the maximum input voltage is 8.49V, the maximum output voltage is 8.09V and the minimum output voltage peak value is 2.31V.

A portion of the input wave less than 2.31V is removed or clipped off. This level can be modified by using variable DC power supply in the way that the voltage of the battery does not exceed that of the AC supply. Compare with what you would expect for this circuit based on theoretical calculations. The circuit is called shunt negative clipper with positive bias.

Hands on tip

The frequency response of an oscilloscope limits the accuracy with which waveforms can be accurately displayed. To view pulse waveforms, the frequency response must be high enough for all significant harmonics of the waveform. For example, a 100MHz oscilloscope distorts a 100MHz pulse waveform because the third, fifth, and higher harmonics are greatly attenuated.

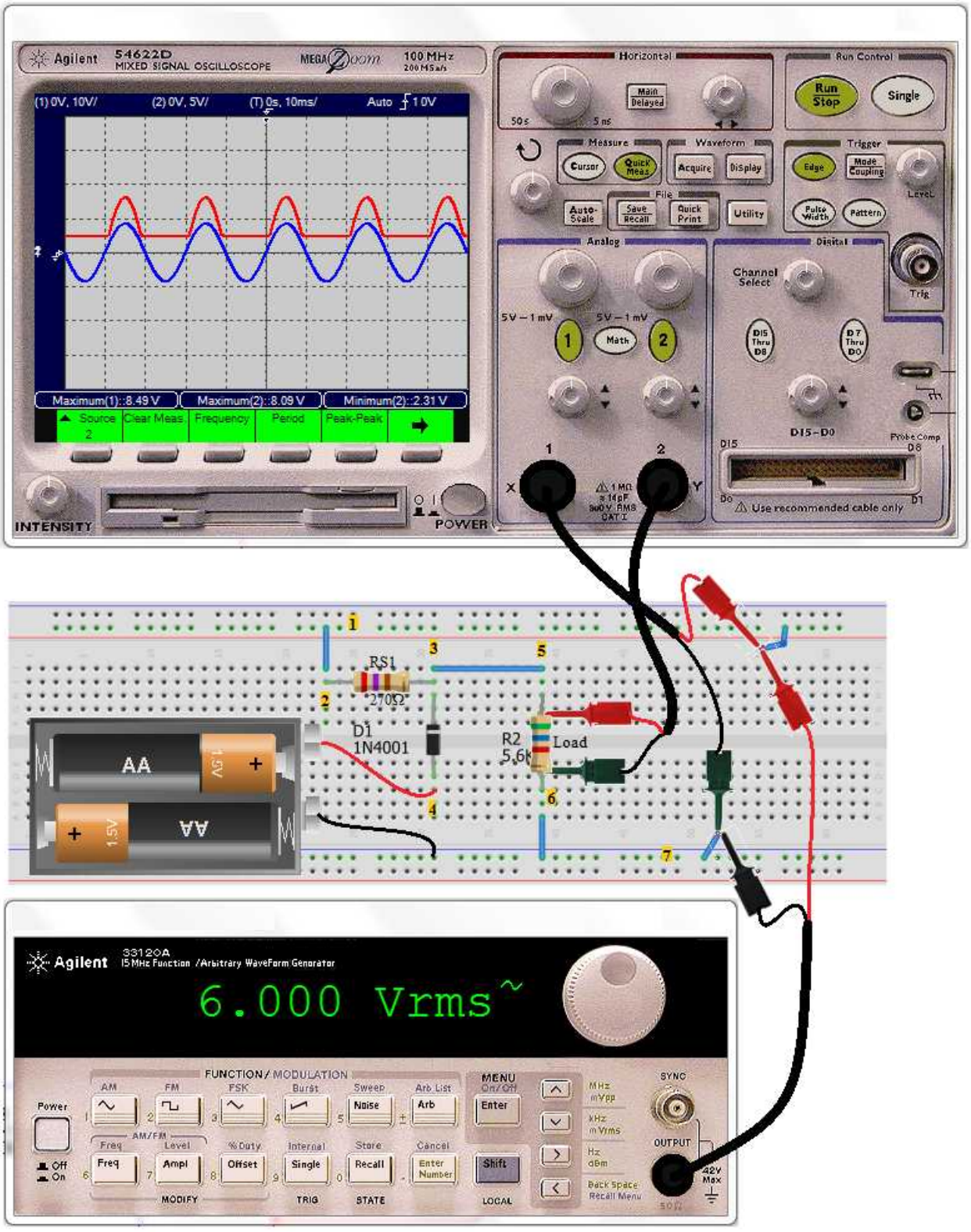


Figure 8-22: Shunt negative clipper with positive bias, real world circuit connection

- **Shunt Negative clipper with negative bias**

If the polarity of the bias voltage is reversed the entire signal below the voltage level is clipped off. At this time, the negative terminal of the battery is connected to the anode of the diode. This keeps the diode to be in reverse bias all along the negative half cycle of the input AC signal until V_{in} becomes greater than V_{bias}. The input signal lying below the battery biasing voltage ($V_{Baterry}$) is clipped off.

Experiment 8-9. Shunt negative clipper with negative bias

In general shunt negative clipper with negative bias is achieved by reversing the polarity of the battery from shunt negative clipper with positive bias as shown in the circuit figure 8-23.

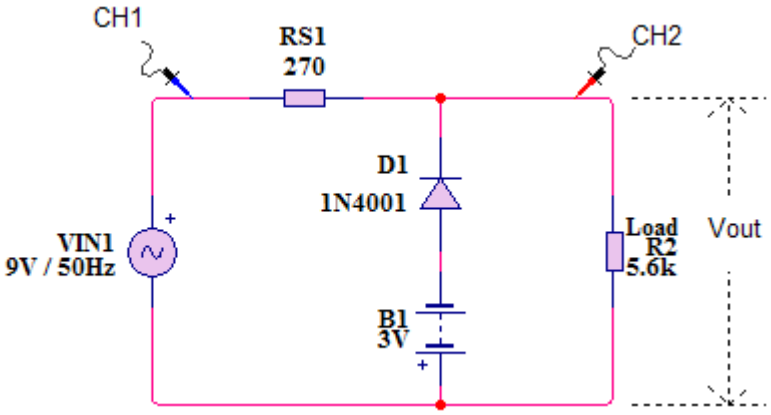


Figure 8-23: Circuit for shunt negative clipper with negative bias

Working Principle of the Circuit

The negative terminal of the battery B_1 reverse biases the diode D_1. The diode remains reversed all along the positive half wave of the incoming input voltage V_{in}. At this time the diode D_1 behaves as an open switch and the input positive diverts to the output. The voltage developed across the load resistor R_2 is calculated by using the Ohm's law. This is given by the equation below.

$$V_{Load} = V_{in} \ [R_{Load}/(R_s+R_{Load})]$$
$$= 6V \ [5.6K\Omega/(270\Omega+5.6K\Omega)]$$
$$=5.72V$$

The maximum voltage is given by: $V_{rms}*\sqrt{2} = 5.72V*1.414$
$$= 8.09V$$

For a negative half wave, the diode D_1 stays reversed until the negative wave voltage exceeds the battery's voltage. At V_{in} negative wave greater than the battery bias, the diode D_1 gets forward biased and the minimum voltage on load resistor R_2 is equal to the battery biasing voltage minus the diode voltage drop (–3V–0.7); that is –3.7V.

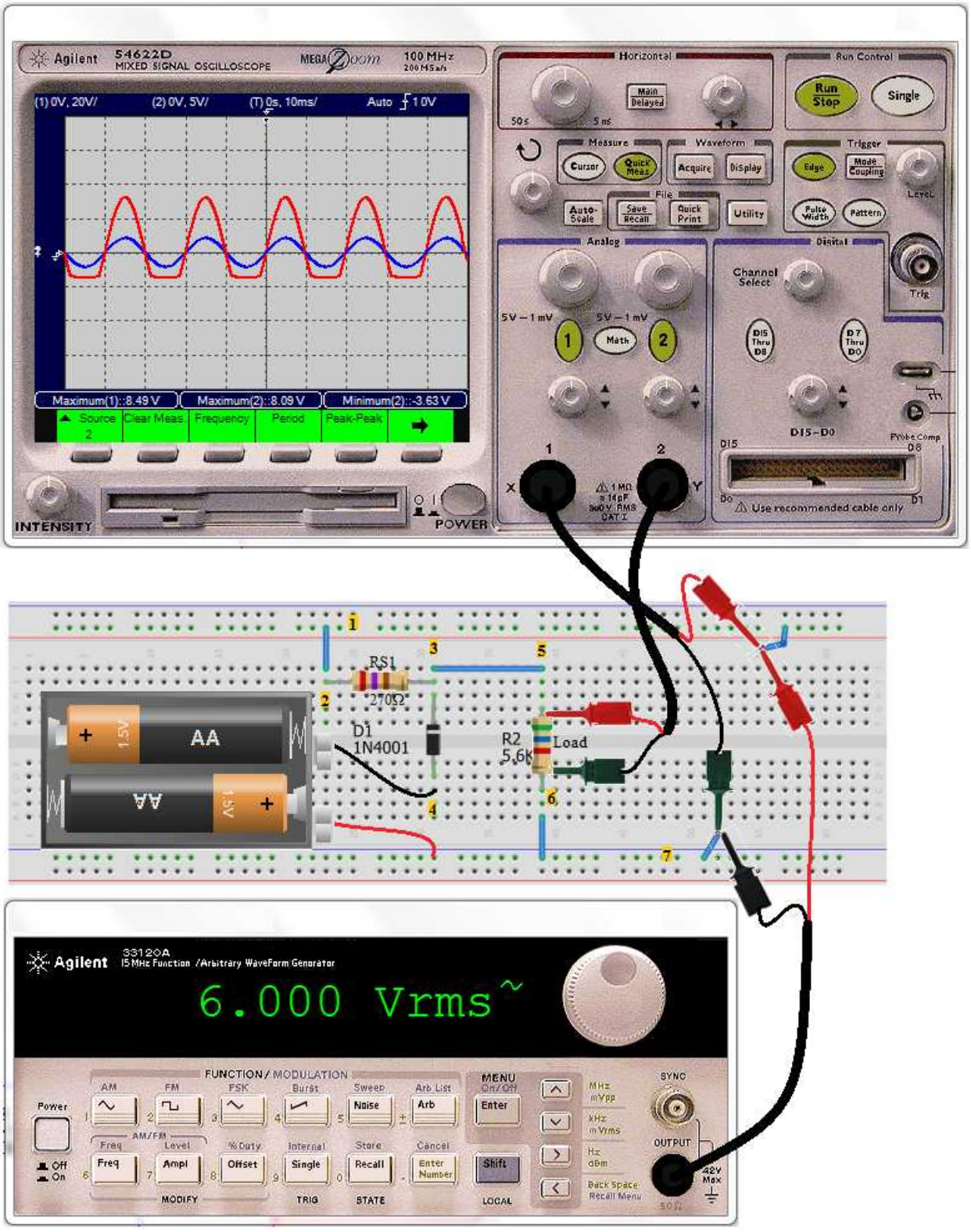


Figure 8-24: Shunt negative clipper with negative bias, real world circuit connection

Procedure

Connect the circuit as illustrated in figure 8-24. The AC supply from function generator is plugged on power bus and ground (1-7) of breadboard. The red lead from a function generator is connected to a positive bus of breadboard (1) and black lead to a negative bus (7). The series resistor RS1 is connected to a power bus through a jumper wire (1-2) and to the cathode of diode D1 (3). The negative of the battery is connected to the anode of diode (4) and its positive terminal is connected to negative bus of the breadboard. The load resistor is connected to the cathode of diode (3-4) and to a negative power bus of breadboard (7). The circuit is supplied with 6V rms sinusoidal from a function generator. Channel one (CH1) is at 10Volt/div and channel two at 5Volt/div vertical sensitivity and horizontal sensitivity is at 10mSec/div.

Adjust vertical sensitivity and horizontal sensitivity to make the wave take up most of the screen without chopping any of its amplitude off and in the easy way reading and calculation. The output voltage is taken between the cathode of diode and the negative terminal of the battery. Any accurate adjustment made on vertical or horizontal sensitivity does not affect the result. The oscilloscope should be AC coupled to read the input waveform but should be DC coupled to read the output waveform.

The channel one (CH1) of oscilloscope is displaying the input AC voltage waveform while the channel two (CH2) is displaying the resulting output voltage. As result shown from oscilloscope, the maximum input voltage is 8.49V, the maximum output voltage is 8.09V and the minimum output voltage peak value is –3.63V. A portion of the input wave less than –3.63V is removed or clipped off. This level can be modified by using variable DC power supply in the way that the voltage of the battery does not exceed that of the AC supply to avoid any risk of damage of AC supply. the circuit is called shunt negative clipper with negative bias.

8. 3. Dual (combination) diode clipper

Dual diode clipper is electronic circuit used to limit both positive and negative of the input AC signal to a desired amplitude level. It can be dual biased clipper or dual unbiased clipper and these are based on shunt positive and negative clipper combined.

- **Dual polarity unbiased diode clipper**

Dual polarity unbiased diode clipper or simply dual polarity diode clipper combines parallel positive clipper with negative clipper. It uses two diodes connected back to back. One diode becomes forwarded biased for one half cycle of the input voltage while the other is in reverse in return to the next half cycle.

Experiment 8-10. Dual polarity unbiased diode clipper

Design a circuit which limits the incoming input voltage to 0.7V for positive half cycle and to –0.7V for negative half cycle. The circuit is based on combination of positive and negative shunt clippers. The circuit has to be supplied with 3V rms from a sinusoidal source, using 470Ω series resistor and silicon diodes as shown in part list below.

Part list

No	Items	Specifications	Quantity
1	Oscilloscope	Agile oscilloscope 54622D	1
2	3VAC supply	Agilent function generator 33120A	1
3	Resistor	470Ω, ½ watt	1
4	Breadboard	Prototyping board (RSR 03MB102)	1
5	Connecting wire	22-gauge (0.33mm^2)solid wire	40cm
6	Diode	1N4007	2
7	Resistors	560Ω, ½ watt	1

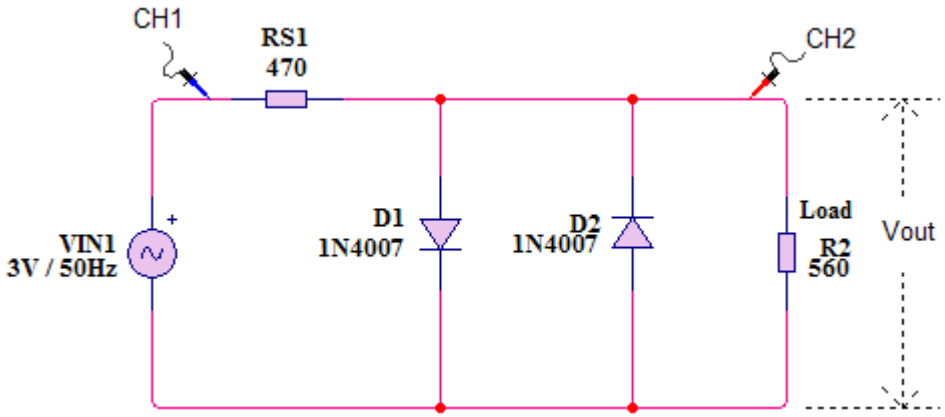


Figure 8-25: Dual polarity unbiased diode clipper

For positive half cycle of the input AC voltage V_{in}, diode D_1 is forward biased whereas D_2 is reversed biased. The current passes through D_1 and voltage across the load resistor R_2 is equal to diode voltage drop (0.7V).

On the other hand, for negative half cycle of the input AC voltage V_{in}, D_2 is in forward bias while D_1 is in reverse bias and acts as open switch. This allows current to pass through D_2 therefore, the voltage developed on load resistor R_2 is equal to the diode voltage drop (–0.7V).

Procedure

Connect the circuit as illustrated in figure 8-26. The AC supply from function generator is connected to power bus and ground (1-9) of breadboard. The red lead from a function generator is connected to a positive bus of breadboard (1) and black lead to ground bus (9). The series resistor R_{S1} is connected to a power bus through a jumper wire (1-2), and to the anode of D_1 (3). A jumper wire interconect the anode of D_1 and cathode of D_2 (3-6).

Both cathode of D_1 (4) and anode of D_2 (5) are connected to ground bus of breadboad (9) through jumper wires. The load resistor R_2 is connected to the cathode of D_2 (5-7) and to ground bus of breadboad through a jumper wire (8-9).

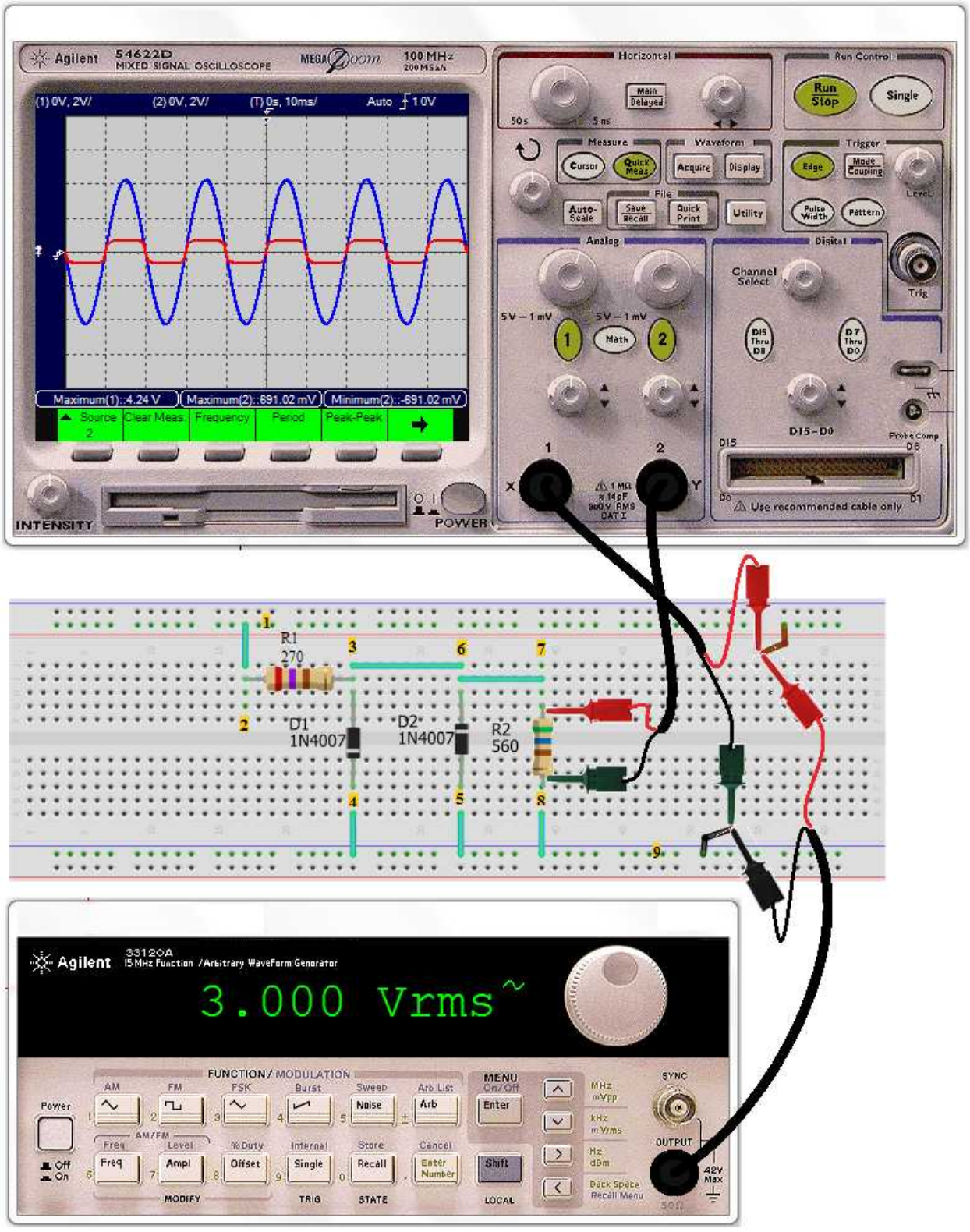

Agilent 54622D MIXED SIGNAL OSCILLOSCOPE 100 MHz
(1) 0V, 2V/ (2) 0V, 2V/ (T) 0s, 10ms/ Auto 1.0V
Maximum(1)::4.24 V Maximum(2)::691.02 mV Minimum(2)::-691.02 mV
Source 2 Clear Meas Frequency Period Peak-Peak
Horizontal Run Control Measure Waveform Trigger File Analog Digital
Run Stop Single Cursor Quick Meas Acquire Display Edge Mode Coupling Auto-Scale Save Recall Quick Print Utility Pulse Width Pattern Channel Select Math Trig Probe Comp
D15-D0 Use recommended cable only
INTENSITY POWER
R1 270
D1 1N4007
D2 1N4007
R2 560
Agilent 33120A 15 MHz Function / Arbitrary Waveform Generator
3.000 Vrms
FUNCTION / MODULATION AM FM FSK Burst Sweep Noise Arb Arb List
MENU On/Off Enter Shift
AM/FM Freq Ampl Offset Single Recall Enter Number
MODIFY TRIG STATE LOCAL
SYNC OUTPUT 42V Max
Power Off On

Figure 8-26: Dual polarity unbiased diode clipper, real world circuit connecrion

The circuit is supplied with 3V rms sinusoidal from a function generator. Both channel one (CH1) and channel two (CH2) are at 2Volt/div vertical sensitivity and 10mSec/div horizontal sensitivity. Adjust vertical sensitivity and horizontal sensitivity to make the wave take up most of the screen without chopping any of its amplitude off and in the easy way reading and calculation. The output voltage is taken between the cathode of diode D_2 and ground bus of breadboard. Any accurate adjustment made on vertical or horizontal sensitivity does not affect the result.

The channel one (CH1 or X) of oscilloscope is displaying the input AC voltage waveform while the channel two (CH2 or Y) is displaying the resulting output voltage. As result shown from oscilloscope, the maximum input voltage is 4.24V, the maximum output voltage is 0.691 mV(0.691 V) and the minimum peak output voltage value is –691 mV (–0.691 V). A portion of the input wave exceeding 0.691 V is removed or clipped off. This level is determined by diode voltage drop and remain unchanged for a wide range of input voltage greater than 0.7V for silicon. The positive and negative are equal in magnitude and have the oposite sign where the name dual polarity diode clipper. The clipping level on both polarities can be modified by using biased dual polarity clippers.

- **Dual polarity biased clipper**

Dual polarity biased clipper circuit can clip at both signal half-cycles (positive and negative half-cycle) in dependent levels depending upon the bias voltages. This combines parallel clipper with negative bias and parallel clipper with positive bias.

Experiment 8-11. Dual polarity biased clipper

Design a circuit which limits positive half cycle of input AC signal to 2.2 V and negative half cycle to –3.7V closer. The circuit is based on parallel clippers with 390 Ω series resistor and 1.8KΩ as load. Use two diodes 1N4005 and other specification provided in part list below.

Part list

No	Items	Specifications	Quantity
1	Oscilloscope	Agile oscilloscope 54622D	1
2	5VAC supply	Agilent function generator 33120A	1
3	Resistors	390Ω, ½ watt	1
4	Resistors	1.8KΩ, ¼ watt	1
5	Breadboard	Prototyping board (RSR 03MB102)	1
6	Connecting wire	22-gauge solid wire	40cm
7	Diode	1N4005	2
8	1.5V DC supply	1.5V AA cell battery	1
9	3V DC supply	2x 1.5V AA cell battery	1

This type of clipper combines a parallel negative clipper with negative bias (D_2 and B_2) and a parallel positive clipper with positive bias (D_1 and B_1). Hence the combination of a biased positive clipper and a biased negative clipper is called combination or dual biased diode clipper. Such a clipper circuit can clip at both two in dependent levels depending upon the bias voltages. The circuit of figure 8-27 shows the circuit of a dual (combination) diode clipper.

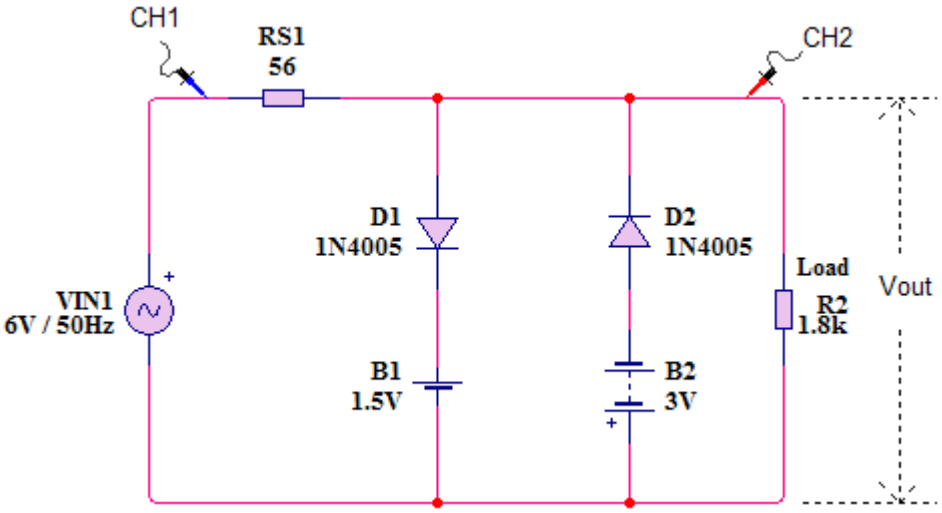


Figure 8-27: Dual (combination) biased diode clipper circuit

A sinusoidal AC input voltage V_{in} is applied at the input terminals of the circuit. During the positive half cycle, the diode D_1 is forward biased, while diode D_2 is reverse biased. Therefore the diode D_1 will conduct and will acts as a short circuit. On the other hand, diode D_2 will acts as an open circuit. However, the value of output voltage cannot exceed the voltage level of battery B_1 plus diode voltage drop (V_{B1}+0.7V).

If V_{B1}= 1.5V

Therefore; V_{B1}+0.7V= 2.2V

This implies that during positive half cycle, the output voltage is equal to 2.2 V

In the same way during the negative input half cycle the diode D_2 acts as a short circuit while the diode D_1 as an open circuit. However the value of output voltage cannot exceed the voltage level of battery B_2 plus diode voltage drop (3V+0.7); value with negative sign.

When V_{B2} = 3V

Then –(3+0.7) = –3.7V

This signifies that during negative cycle, the output voltage is equal to –3.7 V.

It may be noted that the clipping levels of the circuit can be varied by changing the values of biasing voltages V_{B1} and V_{B2}. If the values of V_{B1} and V_{B2} are equal, the circuit will clip both the positive and negative half cycles at the same voltage level. Such a circuit is known as a symmetrical clipper.

Procedure

Connect the circuit as shown in figure 8-28. The AC supply from function generator is plugged to power bus and ground bus (1-9) of breadboard. The red lead from a function generator is connected to a positive bus of breadboard (1) and black lead to ground bus (9). The series resistor R_{S1} is connected to a power bus through a jumper wire (1-2), and to the anode of D_1 (3). A jumper wire interconnects the anode of D_1 and cathode of D_2 (3-6). Cathode of D_1 is connected to positive of battery B_1 (4) and anode of D_2 is connected to negative terminal of the battery B_2 (5).

Both negative terminal of battery B_1 and positive terminal of the battery B_2 are connected to ground bus of breadboad (9). The load resistor R_2 is connected to the cathode of D_2 (5-7) and to ground bus of breadboad through a jumper wire (8-9).

The circuit is supplied with 6V rms sinusoidal from a function generator. Both channel one (CH1) and channel two (CH2) are at 2Volt/div vertical sensitivity and 5mSec/div horizontal sensitivity.

Adjust vertical sensitivity and horizontal sensitivity to make the wave take up most of the screen without chopping any of its amplitude off and in the easy way reading and calculation. Any accurate adjustment made on vertical or horizontal sensitivity does not affect the result. The oscilloscope should be AC coupled to read the input waveform but should be DC coupled to read the output waveform.

The oscilloscope display may have a natural coarseness, which can be reduced by selecting the Average function. Try to use as few samples as possible to avoid long delays while moving from one display to another.

Push the AUTOSCALE button to display both channels. Reposition so that the 0 V is at the midline on the both channels and the waveforms appear to overlap.

At high frequencies, the amplitude of the signal may be too small to be detected by the Autoscale feature. You may need to set the Volts/division and time/division scale manually in order to see the signal. At very high frequencies AUTOSCALE may not work because the filtered signal is too small. Use manual adjustments of the volts/division and time/division to reveal the signal.

The channel one (CH1 or X) of oscilloscope is displaying the input AC voltage waveform while the channel two (CH2 or Y) is displaying the resulting output voltage. Press the MEASURE button to determine the voltage RMS and peak amplitudes for both channels, and make a record.

As result shown from oscilloscope, the maximum input voltage is 7.07 V, the maximum output voltage is 2.24 V and the minimum output voltage peak value is (–3.71 V). A portion of the input wave exceeding +2.24V and –3.71 V is removed or clipped off. These levels are determined by biasing voltage values and can be varied by changing the later. The positive and negative are equal in magnitude and have the oposite sign when the biasing volatge are equal where the name symetric dual polarity diode clipper.

Compare with what you would expect for this circuit based on theoretical calculations.

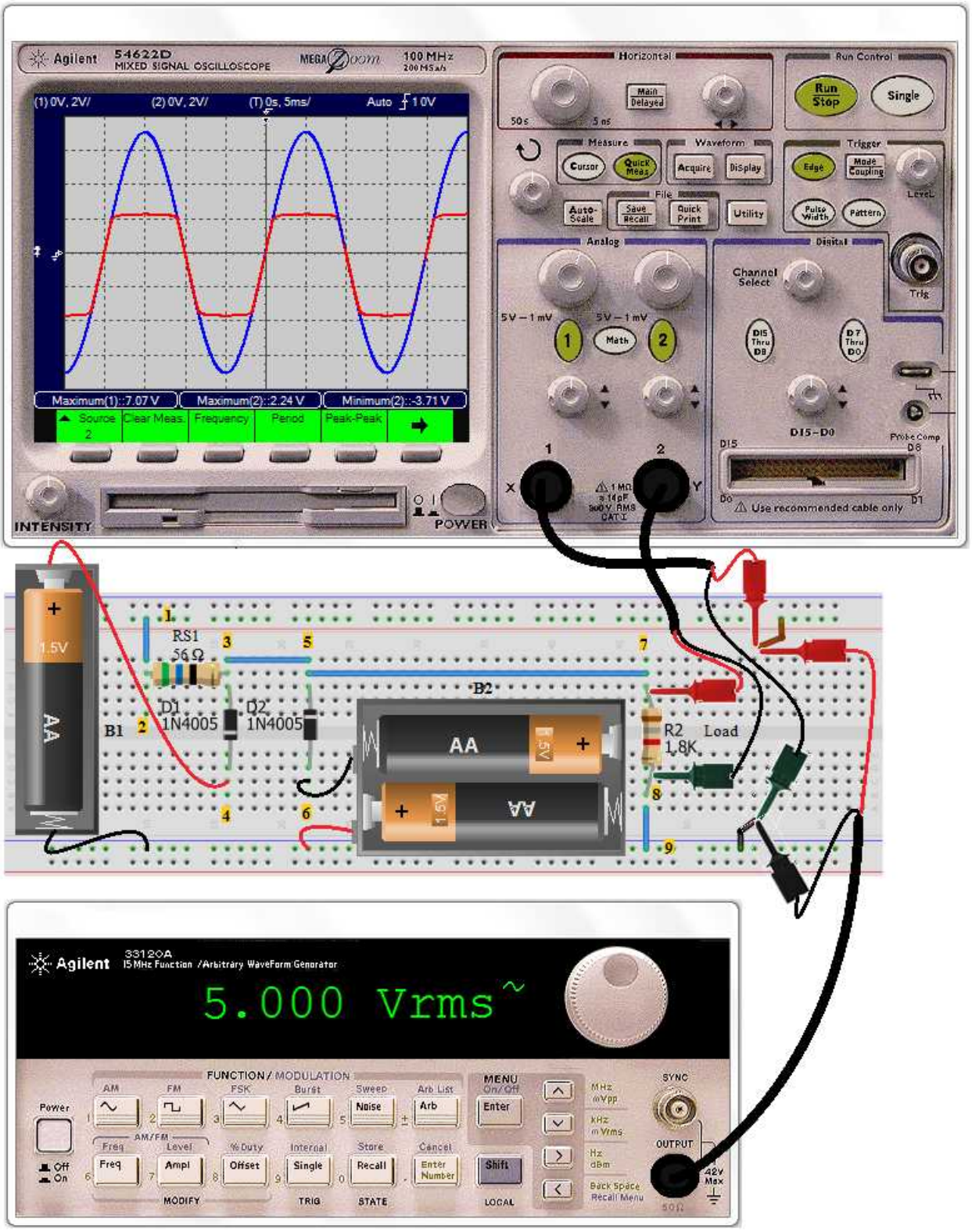


Figure 8-28: Dual (combination) biased diode clipper, real world circuit connection

8. 4. Voltage clipper using zener diode

A zener diode replaces both the diode and the DC voltage source. The use of a bias voltage helps to clip off a certain amount of voltage waveform and this can be accurately controlled. One of the main disadvantages of using voltage biased diode clipping circuits is that they need an additional emf (electromotive force) battery source which may or not be a problem. One easy way of creating biased diode clipping circuits without the need for an additional dc supply is to use Zener diodes.

The zener diode is a special diode that has been specially manufactured to operate in its reverse biased breakdown region and as such can be used for voltage regulation or zener diode clipping applications.

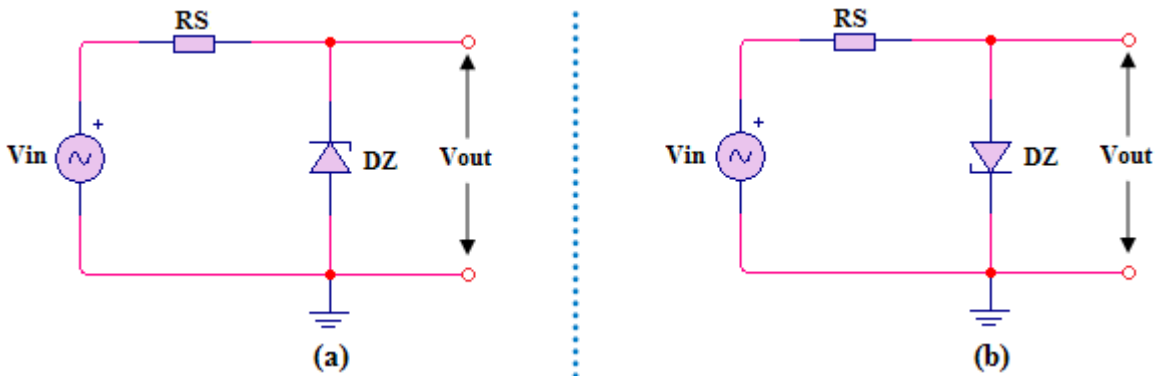


Figure 8-29: Base circuit for voltage clipper using Zener diode; (a) Negative clipper, (b) Positive clipper

When forward biased, the zener acts just like an ordinary silicon diode with a forward voltage drop of 0.7V (700mV). On the other hand, if the zener diode is reversed biased, the voltage is blocked until the zener diode breakdown voltage is reached. At this point, the reverse current through the zener increases sharply but the zener voltage (V_Z) across the device remains constant even if the zener current (I_Z) varies. Thus, we can exploit this characteristic of zener diode and use them for clipping a waveform.

Zener diodes are manufactured with a wide range of voltages and can be used to give different voltage references on each half cycle, the same as above. Zener diodes are available with zener breakdown voltages, V_Z ranging from 2.4 to 33 volts, with a typical tolerance of 1 or 5%. Note that once conducting in the reverse breakdown region, full current will flow through the zener diode so a suitable current limiting resistor, Rs must be chosen.

Experiment 8-12. Positive and negative voltage clipping using zener diode

Design positive and negative voltage clipping circuit using zener diode. Display and measure the resulting waveform on oscilloscope. Supply the circuit with a sinusoidal voltage of 5V/50Hz rms.

Part list

No	Item	Specification	Quantity
1	Zener diode	BZX55C,3V0 zener diode	1
2	Function generator	Agilent 33120A	1

3	Oscilloscope	Tektronix TDS2024	1
4	56 Ω series resistor and 8.2KΩ as load	56Ω, ½ watt; 8.2KΩ ½ watt	1
6	Breadboard	Prototyping board 390-pin	1
7	Connecting wires	22-gauge (0.33mm^2) solid wire	10cm

Negative Clipper

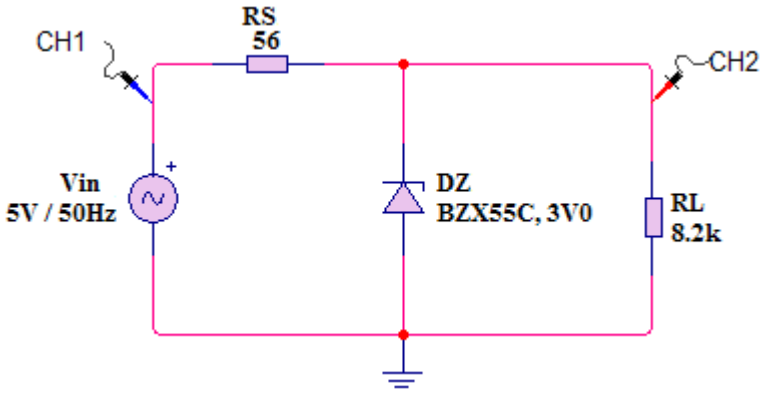


Figure 8-30: Negative clipping circuit using zener diode

Working Principle of the Circuit

Refer to the figure 8-30; the zener diode is acting like a biased diode clipping circuit with the bias voltage being equal to the zener breakdown voltage. In this circuit during the positive half of the input waveform the zener diode is reverse biased so the waveform is clipped at the zener voltage, V_Z equal to 3.0V. During the negative half cycle the zener acts like a normal diode with its usual 0.7V junction value.

Positive Clipper

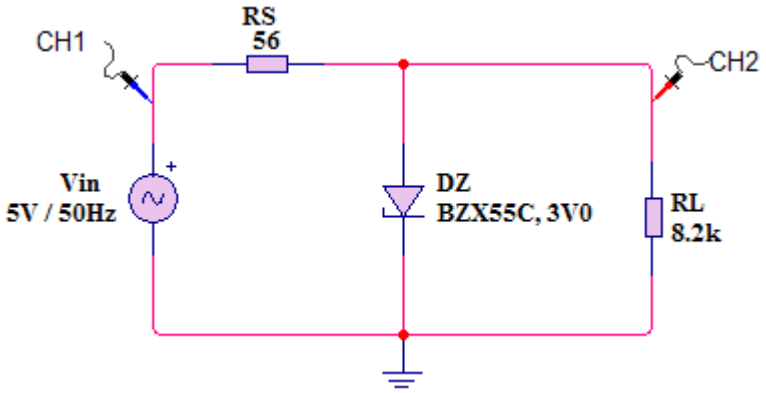


Figure 8-31: Negative clipping circuit using zener diode

Working Principle of the Circuit

For the figure 8-31; the zener diode is acting like a biased diode clipping circuit with the bias voltage being equal to the zener breakdown voltage. During the positive half of the waveform the

zener diode is forward biased and behaves as normal diode with 0.7V as diode voltage drop. When the input voltage reveres direction to the negative half cycle, the zener diode is reverse biased so the waveform is clipped at the zener voltage, V_Z equal to –3.0V.

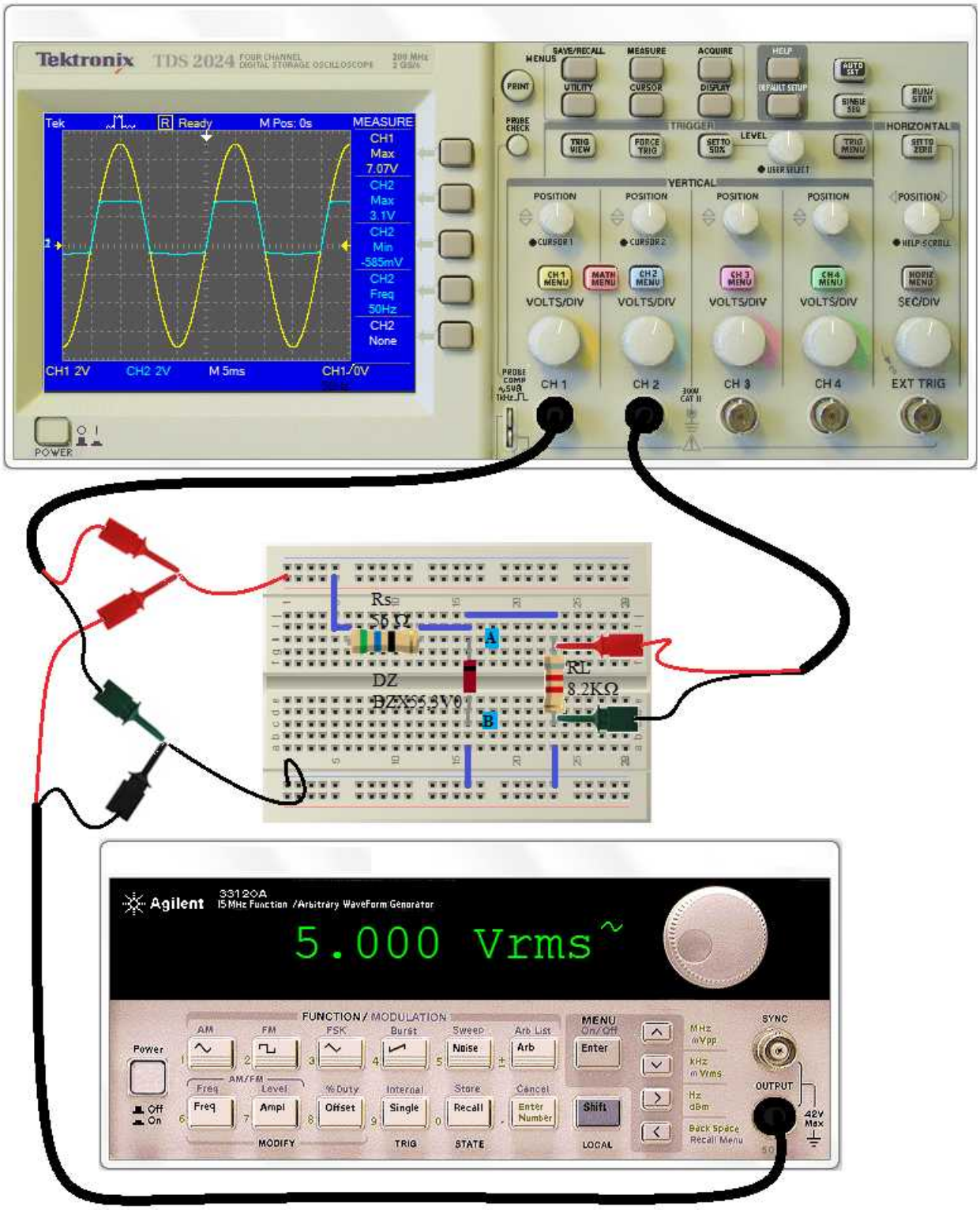


Figure 8-32: Negative clipping circuit using zener diode, real world circuit connection

Procedure

1. Choose 56 Ω series resistor, 8.2KΩ as load resistor and BZX55C3V0 zener diode and connect the circuit as illustrated in figure 8-32
2. Set the function generator to output 5V rms at 50Hz. The input voltage and frequency may change at desired value in the way that the working principle remains unchanged. For a diode to be forward biased, the input voltage needs to be greater than 0.7V
3. Set channel one and channel two (CH1 and CH2) of oscilloscope to 2Volt/div and to 5mSec/div vertical sensitivity and horizontal sensitivity respectively. The oscilloscope should be AC coupled to read the input waveform but should be DC coupled to read the output waveform.

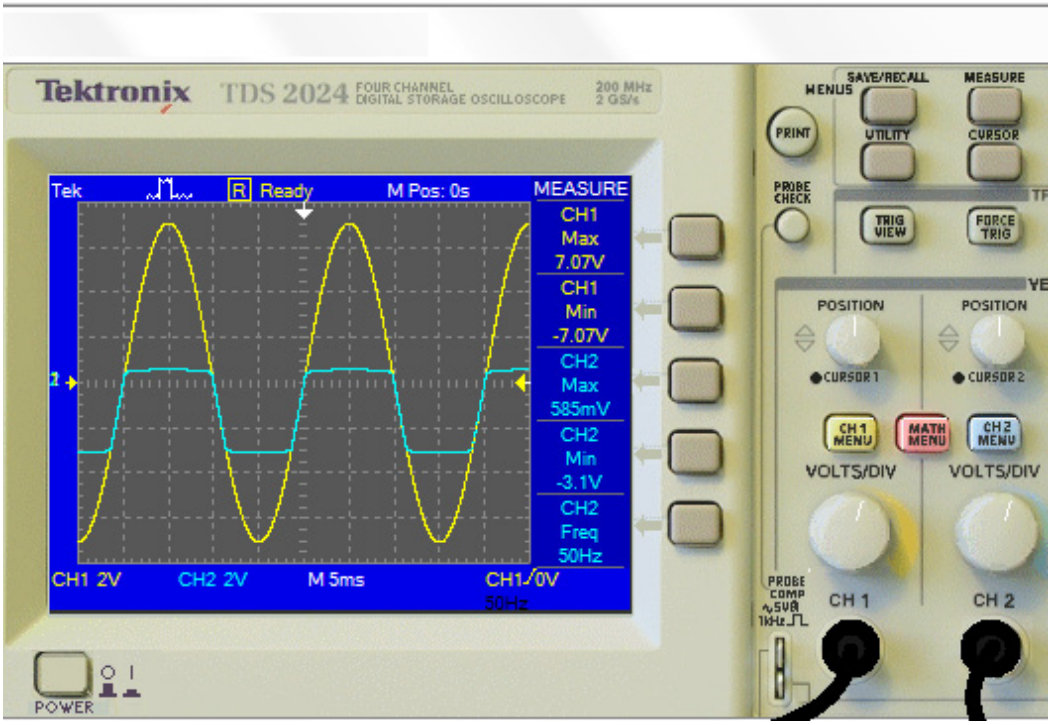


Figure 8-33: Waveform for positive clipper using zener diode

4. The oscilloscope display may have a natural coarseness, which can be reduced by selecting the Average function. Try to use as few samples as possible to avoid long delays while moving from one display to another.
5. Push the AUTOSCALE button to display both channels. Reposition so that the 0V is at the midline on the both channels and the waveforms appear to overlap.
6. At very high frequencies AUTOSCALE may not work because the filtered signal is too small. Use manual adjustments of the volts/division and time/division to reveal the signal. At least one full period of the waveform must be in view to for the oscilloscope measure functions to be accurate.
7. As measured by the oscilloscope, the output voltage varies between 3.1V and -0.585V (585mV) maximum and minimum volts respectively. The resulting is positive voltage clipper.

8. By changing the position of zener diode (anode at point B and cathode at point A), the output voltage varies between 0.585V (585mV) and –7.07V maximum and minimum volts respectively. The resulting is negative voltage clipper as shown in resulting waveform figure 8-33.

Dual Polarity Zener Clipper

Whenever required to remove a portion of both positive and negative half-cycle of the input voltage waveform, the zener diodes can be configured in series back-to back. The clipping level is controlled by reverse breakdown voltage of the zener diode and can be modified by replacing the zener of different breakdown voltage. The base circuit is shown in figure 8-34.

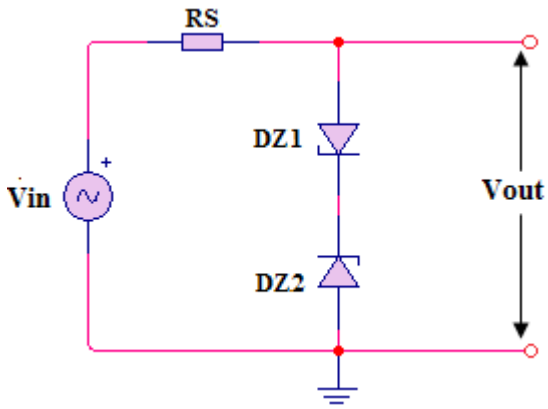


Figure 8-34: Base circuit for dual polarity voltage clipper using zener diode

Working Principle of the Circuit

The output waveform from full wave zener diode clipping circuits resembles that of the previous voltage biased diode clipping circuit. The output waveform will be clipped at the zener voltage plus the 0.7V forward volt drop of the other diode. So for example, the positive half cycle will be clipped at the sum of zener diode, ZD_1 plus 0.7V from ZD_2 and vice versa for the negative half cycle.

Experiment 8-13. Dual polarity voltage clipping using zener diode

Design a voltage clipping circuit using zener diode which can limit both positive and negative half cycle of the input ac supply at 5.4V and -3.4V respectively. Display and measure the resulting waveform on oscilloscope. Supply the circuit with a sinusoidal voltage of 5V/50Hz rms.

Part list

No	Item	Specification	Quantity
1	Zener diode	BZX55C,2V7; BZX55C,4V7	2
2	Function generator	Agilent 33120A	1
3	Oscilloscope	Tektronix TDS2024	1
4	27Ω series resistor and 4.7KΩ as load	27Ω, ½ watt; 4.7KΩ ½ watt	1

6	Breadboard	Prototyping board 390-pin	1
7	Connecting wires	22-gauge (0.33mm^2) solid wire	10cm

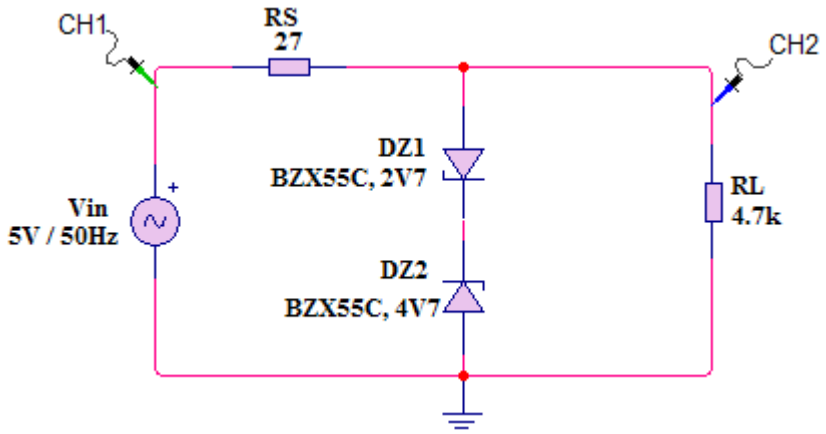


Figure 8-35: Circuit for dual polarity voltage clipper using zener diode

Working Principle of the Circuit

The full wave zener diode clipper of the figure 8-35 uses two diodes connected back-to-back. The output voltage is taken across the terminals of the two diodes. The first zener diode DZ_1 has breakdown voltage of 2.7V whilst the second has breakdown voltage of 4.7V. For positive half cycle, diode DZ_1 is forward biased with 0.7V as diode voltage drop while the second zener diode DZ_2 is reversed biased. Therefore, the output voltage is equal to 0.7V+ V_{DZ2} (0.7V+4.7V), i.e. 5.4V. During the negative half cycle, diode DZ_2 is forward biased and makes voltage drop of 0.7V at the same time, diode DZ_1 is reversed biased and maintain its breakdown voltage of 2.7V. Thus, the output voltage is equal to –(0.7V+2.7V), that is –3.4V. This means that the output voltage will swing between 5.4V and –3.4V maximum and minimum voltage respectively.

Procedure

1. Choose 27 Ω series resistor, 4.7KΩ as load resistor and BZX55C2V7, BZX55C4V7 zener diodes and connect the circuit as illustrated in figure 8-36
2. Set the function generator to output 5V rms at 50Hz. The input voltage and frequency may change at desired value in the way that the working principle remains unchanged. In this case, you need to supply the circuit with voltage greater than 0.7V so that the diode may be forward biased.
3. Set channel one and channel two (CH1 and CH2) of oscilloscope to 2Volt/div and to 5mSec/div vertical sensitivity and horizontal sensitivity respectively.
4. The oscilloscope should be AC coupled to read the input waveform but should be DC coupled to read the output waveform.
5. Try to use as few samples as possible to avoid long delays while moving from one display to another.

6. Push the AUTOSCALE button to display both channels. Reposition so that the 0V is at the midline on the both channels and the waveforms appear to overlap.

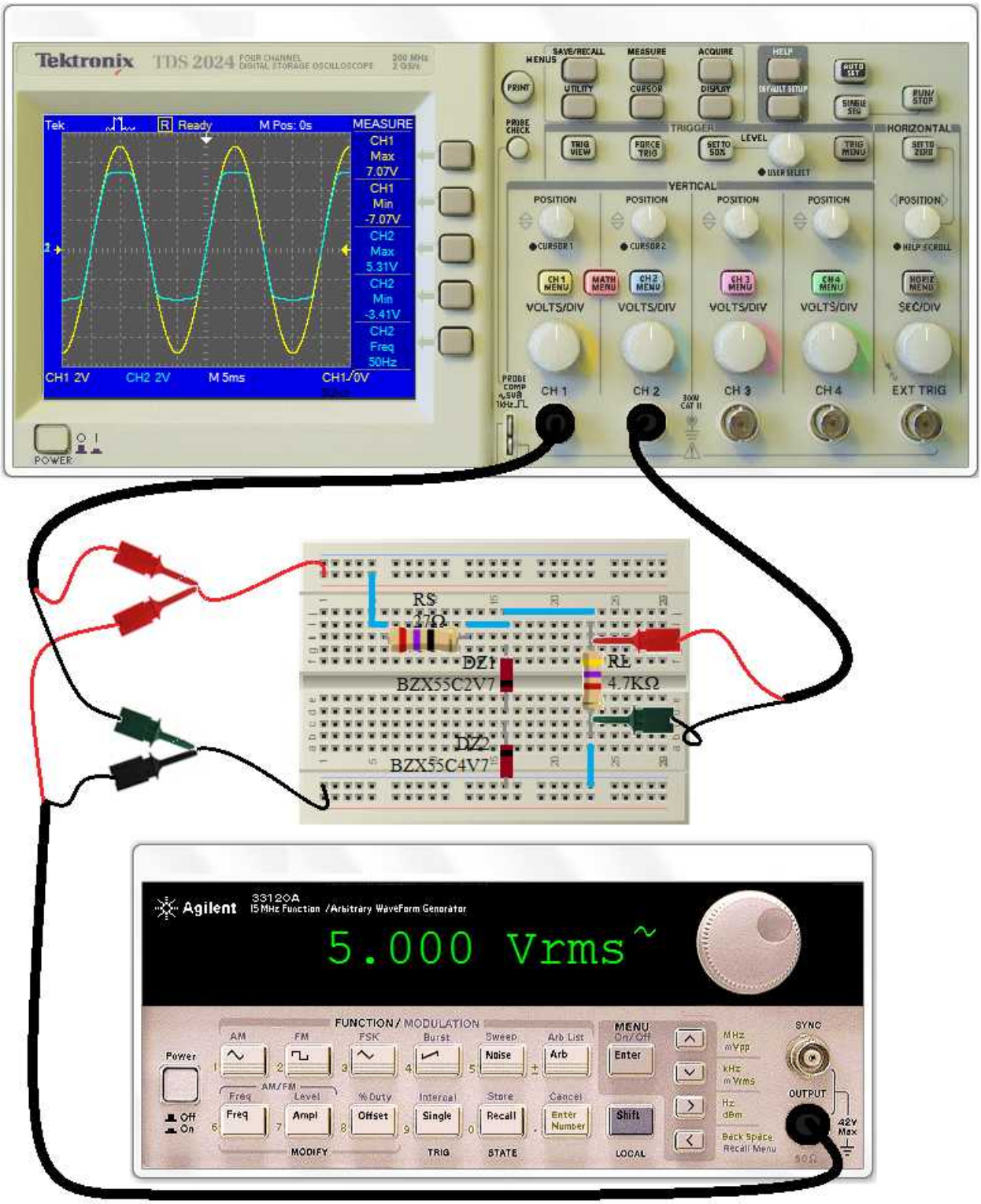


Figure 8-36: Dual polarity clipping circuit using zener diode, real world circuit connection

7. At very high frequencies AUTOSCALE may not work because the filtered signal is too small. Use manual adjustments of the volts/division and time/division to reveal the signal. At least one full period of the waveform must be in view for the oscilloscope measure functions to be accurate.
8. As measured by the oscilloscope, the output voltage varies between 5.31V and –3.41V maximum and minimum volts respectively. The resulting gives a full wave (dual polarity) voltage clipping. Note that the deviation of practical result to the expected theoretical result is base on the tolerance of diodes.

8. 5. Applications of voltage clipper

There are numerous applications for diode clippers. They find wide application in television receiver for separating synchronizing signals from composite picture signals and also in television transmitters at the time of processing the picture signals.

They are also employed for different wave generation such as trapezoidal, square or rectangular waves.

Series clippers are employed as noise limiters in FM transmitters by clipping excessive noise peaks above a specified level.

The diode clipper can be used for the protection of different types of circuits. For example, a digital circuit against transients which may cause considerable damage.

A practical application of a clipper is to prevent an amplified speech signal from overdriving a radio transmitter. Over driving the transmitter generates false radio signals which cause interference with other stations. The clipper is a protective measure. A sine wave may be squared up by overdriving a clipper.

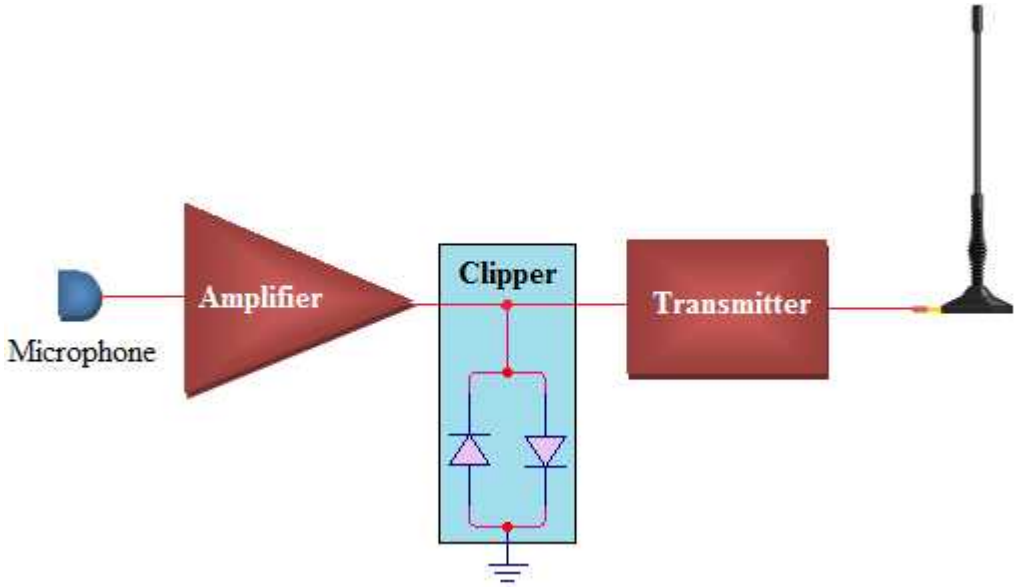


Figure 8-37: Clipper prevents over driving radio transmitter by voice peaks

Chapter nine

Voltage Clamper

Objectives

When you have studied this chapter, you should

- Have an understanding of the working principle of voltage clamping and their applications
- Be capable to design a voltage clamping circuit to a desired DC level

Further reading
Study aids for this chapter are available at
S. P. Bali, *Linear Integrated Circuits*, p.279, Tata McGraw-Hill, 2008

Clamper is an electronic circuit that places either the positive or negative peak of a signal at a desired DC level. The clamper does not restrict the peak-to-peak outing of the signal, it moves the whole signal up or down so as to place the peaks at the reference level. Certain applications in electronics require that the upper or lower extremity of a wave to be fixed at a specific value. In such applications a clamper or clamping circuits are used. Principally a clamping circuit introduces or restores a DC level to an AC signal. The dc component is simply added to or subtracted from the input signal. Hence a clamping circuit in practices is also given other names such as DC restorer, or DC reinserted or a baseline stabilizer. A diode clamp (a simple, common type) consists of a diode, which conducts electric current in only one direction and prevents the signal exceeding the reference value; and a capacitor which provides a DC offset from the stored charge. The capacitor forms a time constant with the resistor load which determines the range of frequencies over which the clamper will be effective.

9. 1. Clamper circuits tips

Clamper circuits are categorized according to their mode of operation. Principally there are two types of clamping circuits: negative or positive clamper; and these can be biased or unbiased. A clamper circuit adds the positive or negative dc component to the input signal so as to push it either on the positive side or on the negative side with respect to the ground level.

The following are two general types of clamper.

1. Positive clamper: This occurs when negative peaks raised or clamped to ground or on the zero level. In other words, it pushes the signal upwards so that negative peaks fall on the zero level.

   For positive biased clamper, the circuit outputs a purely positive waveform from an input signal; it offsets the input signal so that all of the waveform is greater than 0 V.

2. Negative clamper: negative clamping occurs when positive peaks dropped or clamped to ground or on the zero level. In other words, it pushes the signal downwards so that the positive peaks fall on the zero level.

   For negative biased clamper, the circuit outputs a purely negative waveform from an input signal; it offsets the input signal so that all of the waveform is less than 0 V.

Whatever positive or negative clamper the shape of the original signal has not changed; only there is vertical shift in the signal. For a clamping circuit at least three components such as diode, a capacitor and a resistor are required. Sometimes an independent dc supply is also required to cause an additional shift.

9. 1. 1. Working principles

The schematic of a clamper comprises a capacitor, followed by a diode in parallel with the load. The clamper circuits rely on a change in the capacitor's time constant; this is the result of the diode changing current path with the changing input voltage. The magnitude of resistor (R) and capacitor (C) are chosen so that the time constant, $\tau = RC$, is large enough to ensure that the voltage across the capacitor does not discharge significantly during the diode's non-conducting interval since this can affect the output signal. On the other hand the capacitor is chosen small enough to allow it to charge quickly during the diode's conducting interval. During the first negative phase of the AC input voltage, the capacitor in the positive clamper charges rapidly. As V_{in} becomes positive, the capacitor serves as a battery; since it has stored the equivalent of V_{in} during the negative cycle, it provides nearly that voltage during the positive cycle; this essentially doubles the voltage seen by the load. As V_{in} becomes negative, the capacitor acts as a battery of the same voltage of V_{in}. The voltage source and the capacitor neutralize each other, resulting in a net voltage of zero as seen by the load.

9. 1. 2. Clamper circuit practical considerations

When designing clamper circuits, there are key points that have to be considered. These key points are described below.

1. The shape of the waveform will be the same, but its level is shifted either upward or downward.

2. There will be no change in the peak-to-peak or rms value of the waveform due to the clamping circuit. Thus, the input waveform and output waveform will have the same peak-to-peak value that is, $2V_{max}$. This is shown in the figure above. In clamper circuits the same readings will be obtained in the ac voltmeter for the input voltage and the clamped output voltage.
3. There will be a change in the peak and average values of the waveform. For example, the input waveform having a peak value of 6V maximum value and 0V average value over a complete cycle, the clamped output varies from 0V and 12V as peak value (or 0 and -12V for negative clamper) and average value of 6V (or -6V for negative clamped wave) . Thus the peak value of the clamped output is $2V_{max}$ and average value is V_{max}.
4. The circuit containing resistor *R* and capacitor *C*, the values of the resistor *R* and capacitor *C* affect the waveform.
5. The values for the resistor *R* and capacitor *C* should be determined from the time constant equation of the circuit, $\tau = RC$. The values must be large enough to make sure that the voltage across the capacitor *C* does not change significantly during the time interval the diode is not conducting. In a good clamper circuit, the circuit time constant $\tau = RC$ should be at least ten times the time period of the input signal voltage.
6. The signal out of a clamper appears having one peak clamped to a DC voltage. Example: The negative peak is clamped to 0 VDC, the waveform appears to be shifted upward. The polarity of the diode determines which peak is clamped.

It is advantageous to first consider the condition under which the diode becomes forward biased. A capacitively coupled signal alternates about its average DC level (0 V).

9. 2. Positive clamper

Positive clamper circuit raises the input AC signal so that oscillates above the zero level. In such circuit, the negative crest coincides the ground level or above zero. By using DC voltage source, the clamper can be biased to bind the output voltage to a different values. Positive clamper circuit consists mainly of a diode and a capacitor. The diode arrow points upward, again the same direction as the DC shifts. It means that, when the diode points upward we have a positive DC clamper circuit.

Experiment 9-1: Positive clamper

Build a circuit which shifts the input sinusoidal signal to oscillate above the ground level so that the negative peak touches the ground level. With the same principle insert a biasing voltage so that the resulting output wave oscillates above 2V from ground level.

The circuit has to be supplied by 6V rms from a sinusoidal source and feed to a load of 3.9KΩ resistor. The circuit has to be built using 47uF and other items specified in list below and display the resulting waveforms on oscilloscope.

Part list

No	Items	Specifications	Quantity
1	Oscilloscope	Agile oscilloscope 54622D	1
2	6VAC supply	Agilent function generator 33120A	1
3	Resistors	3.9KΩ, ½ watt	1
4	Breadboard	Prototype breadboard	1
5	Connecting wire	22-gauge solid wire	40cm
6	Diode	1N4007	1
7	Capacitor	47µF/50V Capacitor	1
8	3VDC supply	2x1.5AA cell battery	1

- **Unbiased positive clamper**

Refer to the circuit example of figure 9-1, the values used on this circuit can be modified for any desired result. During the negative half cycle of the input voltage V_{IN1}, the diode D_1 is forwarded biased thus conducts heavily and behaves as a closed switch. As result of this, the capacitor C_1 is charged to somewhat maximum input voltage beyond the negative peak voltage i.e.,$-V_{max}$. Once the capacitor is fully charged to $-V_{max}$ it cannot discharge because the diode cannot conduct in the reverse direction.

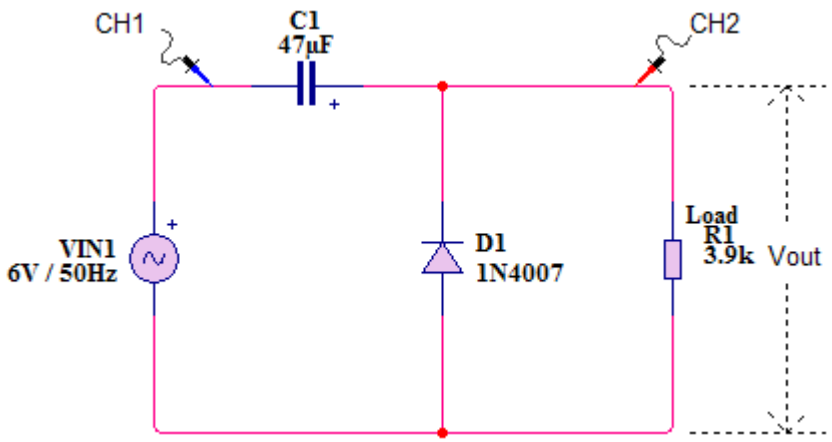


Figure 9-1: Positive clamper circuit

When the input signal changes the direction to the positive half cycle, the diode is shunt off and the capacitor charged to $-V_{max}$ behaves as a battery. It means that this capacitor acts as a battery with an electromotive force (emf) equal to the $-V_{max}$. The polarity of this voltage is such that it adds to the input signal V_{in}. Therefore the output voltage is equal to the sum of the AC input signal and the capacitor voltage V_C i.e., $V_{in} + V_{max}$.

For V_{in} = 6V (rms value);

The capacitor C_1 will be charged to: $V_c = V_{in} * \sqrt{2}$

$= 6V * 1.414 = 8.4853V$

The output peak voltage value:

$$V_{out(max)} = V_{in(max)} + V_c = V_{in(max)}*2$$
$$= 8.4853*2 = 16.9706V$$

The output minimum voltage: $V_{out(min)} = 0V$

The result gives positive clamped voltage where the positive clamping circuit.

Procedure

Connect the circuit as illustrated in figure 9-2. Plug the leads of AC supply from function generator to power bus and ground bus (1-8) of breadboard. The red lead from a function generator is connected to a positive bus of breadboard (1) and black lead to ground bus (8). The capacitor C_1 is connected to a power bus through a jumper wire (1-2), and to the cathode of diode D_1 (3-4). The anode of diode D_1 (5) is connected to ground bus of breadboard through a jumper wire (5-8). The load resistor R_2 is connected to the cathode of D_1 (4) and to ground bus of breadboad through a jumper wire (7-8). The circuit is supplied with 6V rms sinusoidal from a function generator.

Both channel one (CH1) and channel two (CH2) are at 5Volt/div vertical sensitivity and 5mSec/div horizontal sensitivity. Adjust vertical sensitivity and horizontal sensitivity to make the wave take up most of the screen without chopping any of its amplitude off and in the easy way reading and calculation.

The oscilloscope display may have a natural coarseness, which can be reduced by selecting the Average function. Try to use as few samples as possible to avoid long delays while moving from one display to another.

Push the AUTOSCALE button to display both channels. Reposition so that the 0V is at the midline on the both channels and the waveforms appear to overlap.

At high frequencies, the amplitude of the filtered signal may be too small to be detected by the Auto-scale feature. You may need to set the Volts/division and time/division scale manually in order to see the signal.

Any accurate adjustment made on vertical or horizontal sensitivity does not affect the result.

At very high frequencies AUTOSCALE may not work because the filtered signal is too small. Use manual adjustments of the volts/division and time/division to reveal the signal.

The channel one (CH1 or X) of oscilloscope is displaying the input AC voltage waveform while the channel two (CH2 or Y) is displaying the resulting output voltage.

Press the MEASURE button to determine the voltage peak amplitudes for both channels, and make a record.

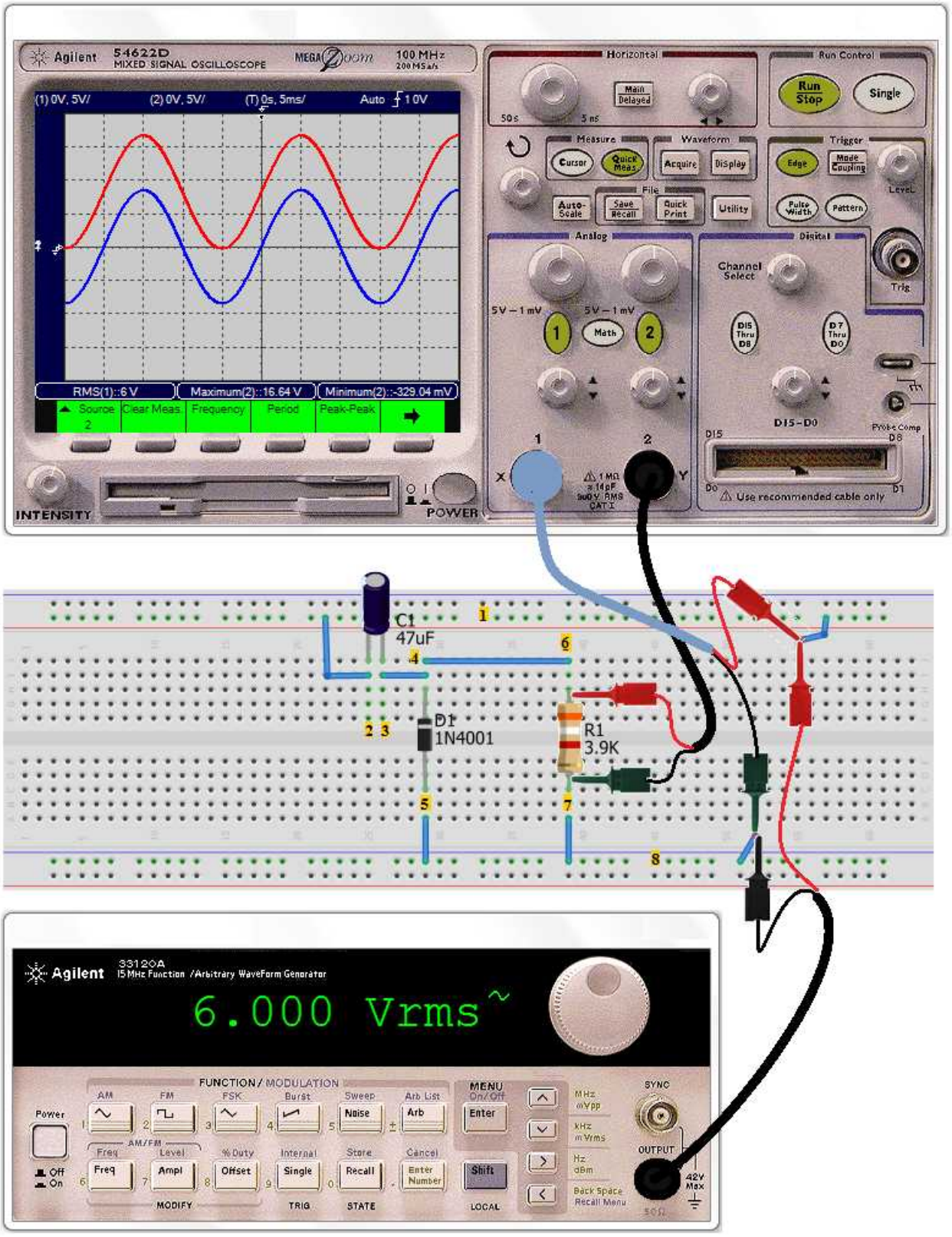


Figure 9-2: Positive clamper, real world circuit connection

As result shown from oscilloscope, the maximum output voltage is 16.64V and the minimum output voltage peak value is (–329.04mV). A portion lower zero level is due to diode voltage drop and theoricaly this is said to be zero.

Compare with what you would expect for this circuit based on theoretical calculations.

- **Positive clamper with bias**

Biased clamper circuit operates in exactly the same manner as unbiased clampers. The different is only that a dc bias voltage is added in series with the diode and resistor. A biased clamper means that the clamping can be done at any voltage level other than zero. With a 3VDC battery in series with a silicon diode gives 2.3V (3V–0.7) if we consider diode voltage drop. This implies that the negative peak of resulting output waveform have to be above 2.3V. The circuit of figure 9-3 shows positive clamper with positive bias.

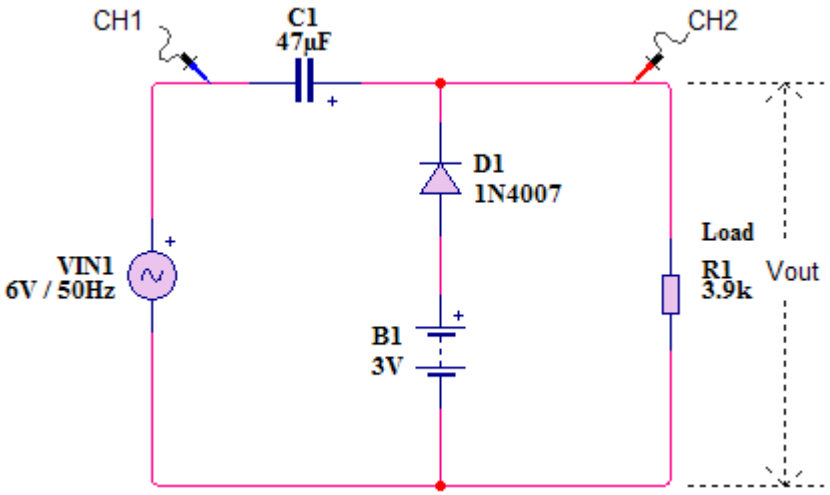


Figure 9-3: Positive clamper with positive bias circuit

In the above circuit, a 3V battery (B_1) is added in such a way that the clamping take place positively from 3V. The positive terminal of the battery keeps diode D_1 forwarded biased and the battery's voltage helps as reference. Reversing battery's polarity downwards a small portion of the input wave below ground level (–3.7V from this circuit. Mainly the offset level is 2.3V. This signifies that the output voltage remains to be 2.3V for absence of input signal.

Procedure

Connect the circuit as illustrated in figure 9-4. Connect the AC supply from function generator to power bus and ground bus (1-8) of breadboard. The red lead from a function generator is connected to a positive bus of breadboard (1) and black lead to ground bus (8). The capacitor C_1 is connected to a power bus of breadboard through a jumper wire (1-2), and to the cathode of diode D_1 (3-4). The anode of diode D_1 is connected to negative terminal of the battery B_1 (5) and the positive terminal is connected to ground bus of (8).

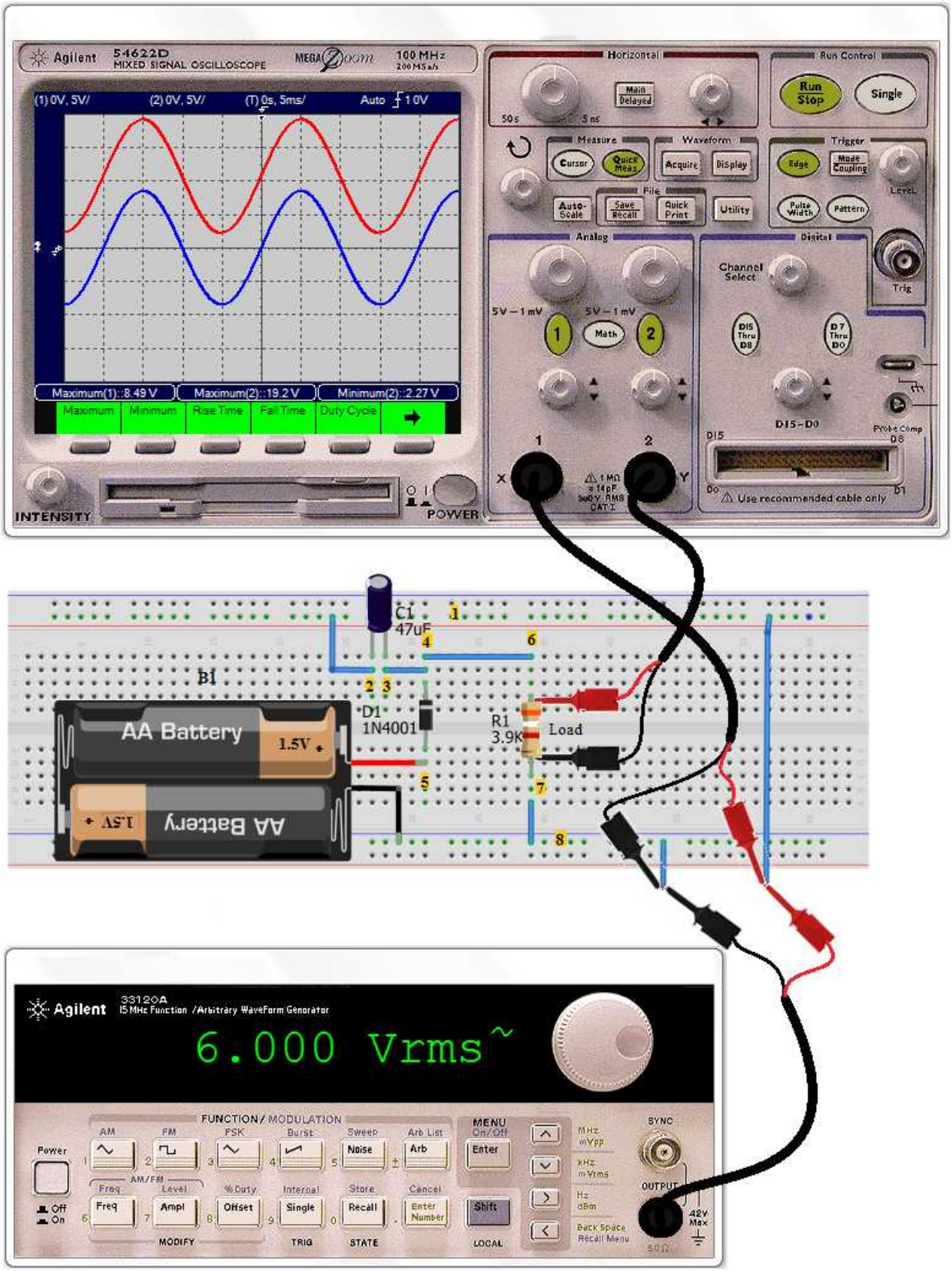


Figure 9-4: Positive clamper with positive bias, real world circuit connection

The load resistor R_1 is connected to the anode of diode D_1 (4-6) and to ground bus of breadboad through a jumper wire (7-8). The circuit is supplied with 6V rms sinusoidal from a function generator. Both channel one (CH1) and channel two (CH2) are at 5Volt/div vertical sensitivity and at 5mSec/div horizontal sensitivity.

Modify caliblation of vertical sensitivity and horizontal sensitivity to make the wave take up most of the screen without cutting any of its amplitude off and in the easy way reading and calculation where necessary. Push the AUTOSCALE button to display both channels. Reposition so that the 0V is at the midline on the both channels and the waveforms appear to overlap.

Any accurate adjustment made on vertical or horizontal sensitivity does not affect the result.

The channel one (CH1 or X) of oscilloscope is displaying the input AC voltage waveform while the channel two (CH2 or Y) is displaying the resulting output voltage. The oscilloscope should be AC coupled to read the input waveform but should be DC coupled to read the output waveform.

Press the MEASURE button to determine the voltage peak amplitudes for both channels, and make a record. Maximum input voltage is 8.49V and the maximum and minimum output voltages measured from oscilloscope are 19.2V and 2.27V respectively. Compare with what you would expect for this circuit based on theoretical calculations.

Similarly, it is possible to clamp the input waveform negatively at –3V (–3.7V since in practice the diode voltage drop has to be taken in account) by reversing the battery connections as shown in the circuit figure 9-5.

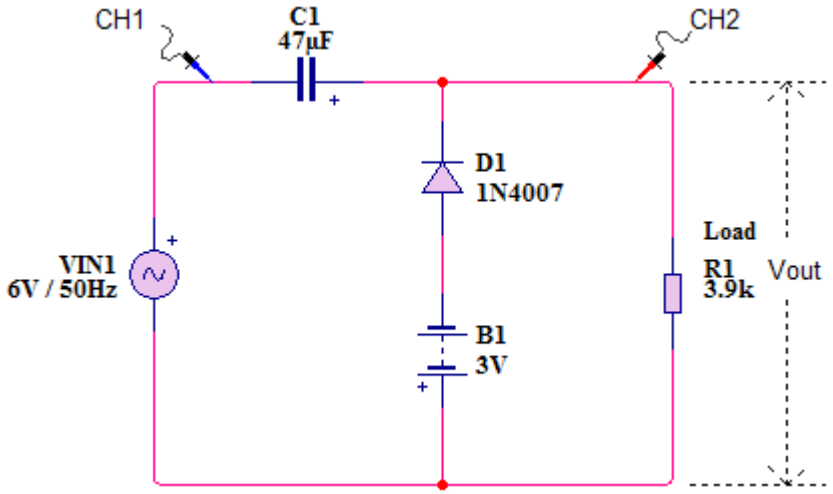


Figure 9-5: Positive clamper with negative bias circuit

The battery's voltage acts as reference level from which the input voltage has to be shifted upwards or downwards. From the above circuit with respect to the orientation of polarities of the battery B_1, the voltage reference is –3V (–3.7V in practice). The negative peak of input signal falls on – 3.7V for any input voltage greater than reference voltage 3V.

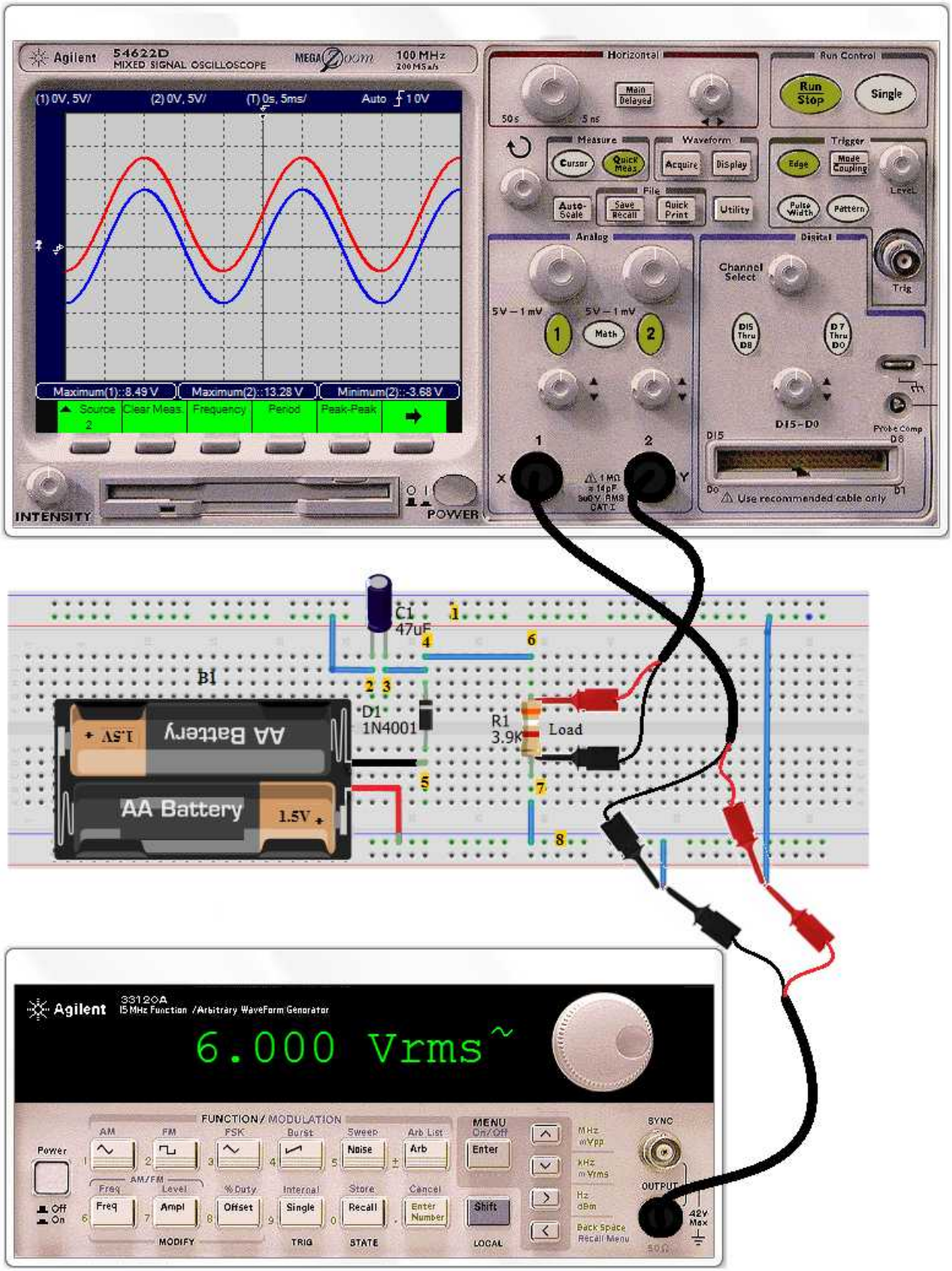


Figure 9-6: Positive clamper with negative bias, real world circuit connection

The maximum and minimum output voltages measured from oscilloscope are 13.28V and –3.68V respectively from 6VAC supply source. The shifted signal is not purely in positive due to the reversing of battery's polarity. for that reason in designing such circuit attention must be taken in case clamping requires the input wave to be shifted entirely in positive or negative with respect to the ground level.

The resulting waveform and the circuit connection on breadboard are shown in the figure 9-6.

9. 3. Negative clamper

Negative clamper is electronics circuit that shifts the original signal in a vertical downward direction. In negative clamping circuit, the positive peak is slumped to level or below zero. By using DC voltage source, the clamper can be biased to bind the output voltage to a different negative values. Negative diode clamper circuit consists mainly of a diode and a capacitor. The diode arrow points downward, all over again the same direction as the DC shifts. This signifies that, when the diode points downward we have a negative clamper circuit.

Experiment 9-2: Negative clamping circuit

Design a circuit which fixes the input sinusoidal signal downwards to oscillate below the ground level. At first the positive peaks on the input signal have to coincide to zero level and at the second to –2V. The average output voltage swing to –8.48V and to –10.48 from the first case and the second case respectively. The circuit has to be built using 100uF capacitor, 2.7KΩ as load resistor. Display the resulting wave forms on oscilloscope.

Finding V_{in} voltage value:

Given: V_{av} (1^{st} case) = – 8.48V

V_{av} (2^{nd} case) = – 10.48V

Formular : $V_{av} = (V_{max}+V_{min})/2$

$$V_{in(Peak\ value)} = V_{(peak\text{-}to\text{-}peak)}/2 = V_{av} - V_{referance}$$

$$V_{in(rms\ value)} = V_{in(Peak\ value)}/\sqrt{2}$$

Where:

- $V_{max:}$ The peak voltage of the positive half cycle
- V_{min}: The peak value of the negative half cycle

For the first case; $V_{referance}$ = 0V;

Therefore, $V_{in(peak)}$ = – 8.48V – 0V = – 8.48V

$$V_{in(rms)} = V_{in(peak)}/(\sqrt{2})$$

$$= (-8.48)/1.4142$$

$$= -6V$$

For the second case; $V_{reference}$ = -2V

Thus, $V_{in(peak)}$ = – 10.48V - (-2V) = – 10.48V + 2V = – 8.48V

Therefore $V_{in(rms)} = V_{in(peak)}/(\sqrt{2})$ = (– 8.48)/1.4142 = – 6V

For the first and the second case, the input voltage (V_{in}) is the same and is equal to 6V in absolute value. From market we get 1.5V or 3V batteries therefore, 2V in practice has to be represented by 3V battery since this gives 2.3V in consideration of diode voltage drop where the part list below.

Part list

No	Items	Specifications	Quantity
1	Oscilloscope	Agile oscilloscope 54622D	1
2	6VAC supply	Agilent function generator 33120A	1
3	Resistors	2.7KΩ, ½ watt	1
4	Breadboard	Prototyping board (RSR 03MB102)	1
5	Connecting wire	22-gauge solid wire	40cm
6	Diode	1N4002	1
7	Capacitor	100µF/50V Capacitor	1
8	3VDC supply	2x1.5AA cell battery	1

- **Unbiased negative clamper**

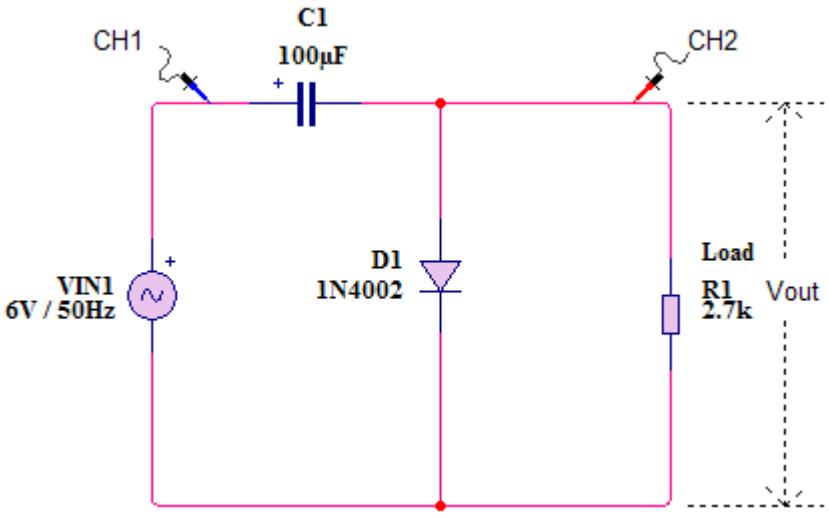


Figure 9-7: Unbiased negative clamper circuit

When the input signal is applied during positive half cycle, the diode D_1 will be forward biased and the capacitor C_1 is charged. During the positive half cycle of input, the output voltage will be equal to the barrier potential of the diode, V_D = 0.7V and the capacitor is charged to (V_{in} – V_D). During the negative half cycle, the diode becomes reversed biased and acts as an open circuit. Thus, there will be no effect on the capacitor voltage. The load resistance R_1, being of very high value, cannot discharge C_1 a lot during the negative portion of the input waveform. Thus, during

negative input, the output voltage will be the sum of the input voltage and the capacitor voltage and is equal to:

$$-V_{in} - (V_{in} - V_D) \text{ or } -(2\,V_{in} - V_D).$$

$$V_{out} = -6*\sqrt{2}-(6*\sqrt{2}-0.7)$$
$$= -8.4853*2 + 0.7$$
$$= -16.9706 + 0.7 = -16.2706V$$

The value of the peak-to-peak output voltage will be the difference of the negative and positive peak voltage levels is equal to:

$$V_D-[-(2V_{in}-V_D)] \quad \text{or} \quad 2\,V_{in}.$$

$$V_{OUT(peak\text{-}to\text{-}peak)} = 0.7V-[-(2*6*\sqrt{2}-0.7V)\,]$$
$$= 0.7-[-(16.9706V-07V)]$$
$$= 0.7V+16.9706V-0.7V$$
$$= 16.9706V$$

Average voltage: $V_{av} = (V_{max}+V_{min})/2 = (0.7V-16.2706)/2 = -7.7853$

Procedure

Connect the circuit as illustrated in figure 9-8. Connect the AC supply from function generator to power bus and ground bus (1-8) of breadboard. The red lead from a function generator is connected to a positive bus of breadboard (1) and black lead to ground bus (8). The capacitor C_1 is connected to a power bus of breadboard through a jumper wire (1-2), and to the anode of diode D_1 (3-4). The cathode of diode D_1 (5) is connected to ground bus of breadboard through a jumper wire (5-8).

The load resistor R1 is connected to the anode of D_1 (4-6) and to ground bus of breadboad through a jumper wire (7-8). The circuit is supplied with 6V rms sinusoidal from a function generator. Both channel one (CH1) and channel two (CH2) are at 5Volt/div vertical sensitivity and at 5mSec/div horizontal sensitivity.

Push the AUTOSCALE button to display both channels. Reposition so that the 0V is at the midline on the both channels and the waveforms appear to overlap.

Change vertical sensitivity and horizontal sensitivity to make the wave take up most of the screen without cutting any of its amplitude off and in the easy way reading and calculation where necessary. Any accurate adjustment made on vertical or horizontal sensitivity does not affect the result.

The channel one (CH1 or X) of oscilloscope is displaying the input AC voltage waveform while the channel two (CH2 or Y) is displaying the resulting output voltage. As result shown from oscilloscope, the maximum output voltage is 708.91mV and the minimum output voltage peak value is (–16.24V) with –7.75V average output voltage. A portion of 708.91mV above groung level is due to diode voltage drop and theoricaly this is said to be zero.

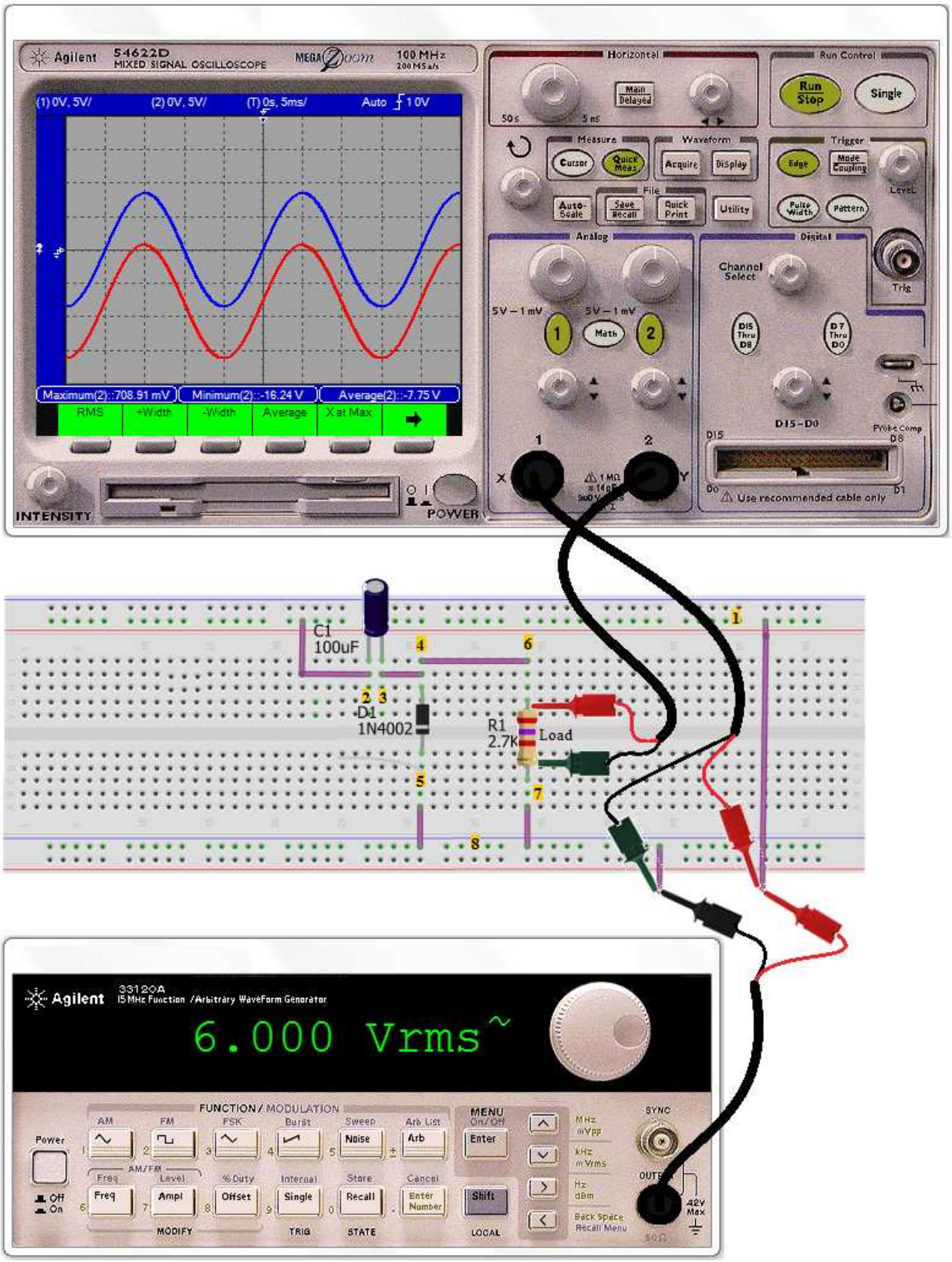


Figure 9-8: Unbiased negative clamper, real world circuit connection

- **Biased negative clamper**

Biased negative clamper is realized by inserting in negative clamper the DC source in series with diode as shown in the circuit figure 9-9.

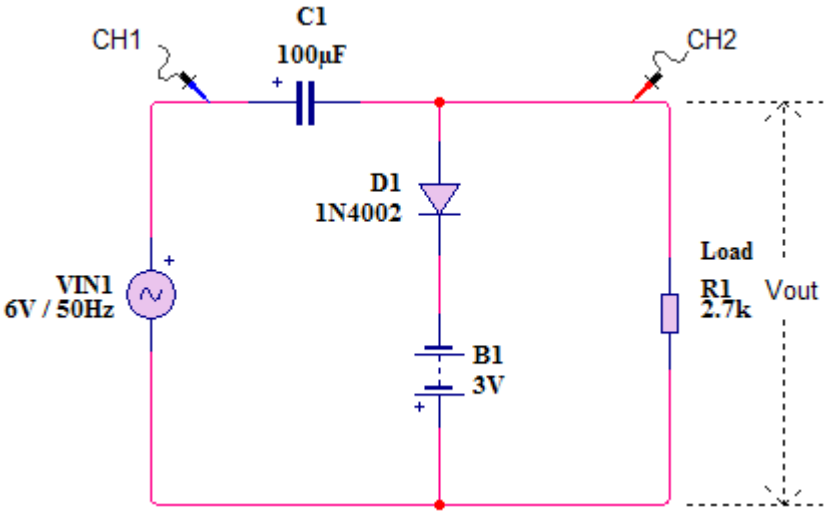


Figure 9-9: Biased negative clamper circuit

When an input signal is applied during positive half cycle, the diode D_1 will be forward biased when V_{IN1} is greater than the battery's B_1 voltage (-3V) and the capacitor C_1 is charged. During the positive half cycle of input, the output voltage will be equal to the barrier potential of the diode plus the battery's voltage, 0.7V+ (-3V) and the capacitor is charged to ($V_{in} - V_D$). During the negative half cycle, the diode becomes reversed biased and acts as an open circuit. Thus, there will be no effect on the capacitor voltage. The load resistance R_1, being of very high value, cannot discharge C_1 a lot during the negative portion of the input waveform. Thus during negative input, the output voltage will be the sum of the input voltage, the capacitor voltage and the batter's voltage and is equal to:

$$-V_{in} - (V_{in} - V_D) - V_{B1} \text{ or } -(2V_{in} + V_{B1} - V_D).$$

$$V_{out} = -6*\sqrt{2} - (6*\sqrt{2} - 0.7) - 3V$$
$$= -8.4853*2 + 0.7V - 3V$$
$$= -16.9706 - 2.3V$$
$$= -19.1706V$$

The value of the peak-to-peak output voltage will be the difference of the negative and positive peak voltage levels is equal to:

$$V_D - V_{B1} - [-(2V_{in} + V_{B1} - V_D)] \text{ or simply } 2V_{in}.$$

$$V_{out(peak\text{-}to\text{-}peak)} = 0.7V - 3V - [(2*6*\sqrt{2} + 3V - 0.7V)]$$
$$= -2.3V - [-(16.9706V + 2.3V)]$$
$$= -2.3 + 16.9706V + 2.3V$$

$$=16.9706V$$

Average voltage: $V_{av} = (V_{max}+V_{min})/2$

$$= ((0.7–3) – (16.2706+3–0.7))/2$$

$$= – 20.8706/2$$

$$= –10.4353V$$

Procedure

Connect the circuit as illustrated in figure 9-10. Plug the AC supply from function generator to power bus and ground bus (1-8) of breadboard. The red lead from a function generator is connected to a positive bus of breadboard (1) and black lead to ground bus (8).

The capacitor C_1 is connected to a power bus of breadboard through a jumper wire (1-2), and to the anode of diode D_1 (3-4).

The cathode of diode D1 is connected to negative terminal of the battery B_1 (5) and the positive terminal is connected to ground bus of (8).

The load resistor R_1 is connected to the anode of diode D_1 (4-6) and to ground bus of breadboad through a jumper wire (7-8).

The circuit is supplied with 6V rms sinusoidal from a function generator. Both channel one (CH1) and channel two (CH2) are at 5Volt/div vertical sensitivity and at 5mSec/div horizontal sensitivity.

Push the AUTOSCALE button to display both channels. Reposition so that the 0V is at the mid-line on the both channels and the waveforms appear to overlap.

Modifying caliblation of vertical sensitivity and horizontal sensitivity to make the wave take up most of the screen without cutting any of its amplitude off and in the easy way reading and calculation where necessary. Any accurate adjustment made on vertical or horizontal sensitivity does not affect the result.

At very high frequencies AUTOSCALE may not work because the filtered signal is too small. Use manual adjustments of the volts/division and time/division to reveal the signal.

At high frequencies, the amplitude of the signal may be too small to be detected by the Auto-scale feature. You may need to set the Volts/division scale manually in order to see the signal.

Press the MEASURE button to determine the maximum and minimum voltages and peak-to-peak amplitudes for both channels, and make a record.

The channel one (CH1 or X) of oscilloscope is displaying the input AC voltage waveform while the channel two (CH2 or Y) is displaying the resulting output voltage. The minimun and peak-to-peak voltages measured from oscilloscope are – 19.14V and 16.89V respectively. The average value measured between the maximum and minimum of output voltage is – 0.67V.

Compare with what you would expect for this circuit based on theoretical calculations.

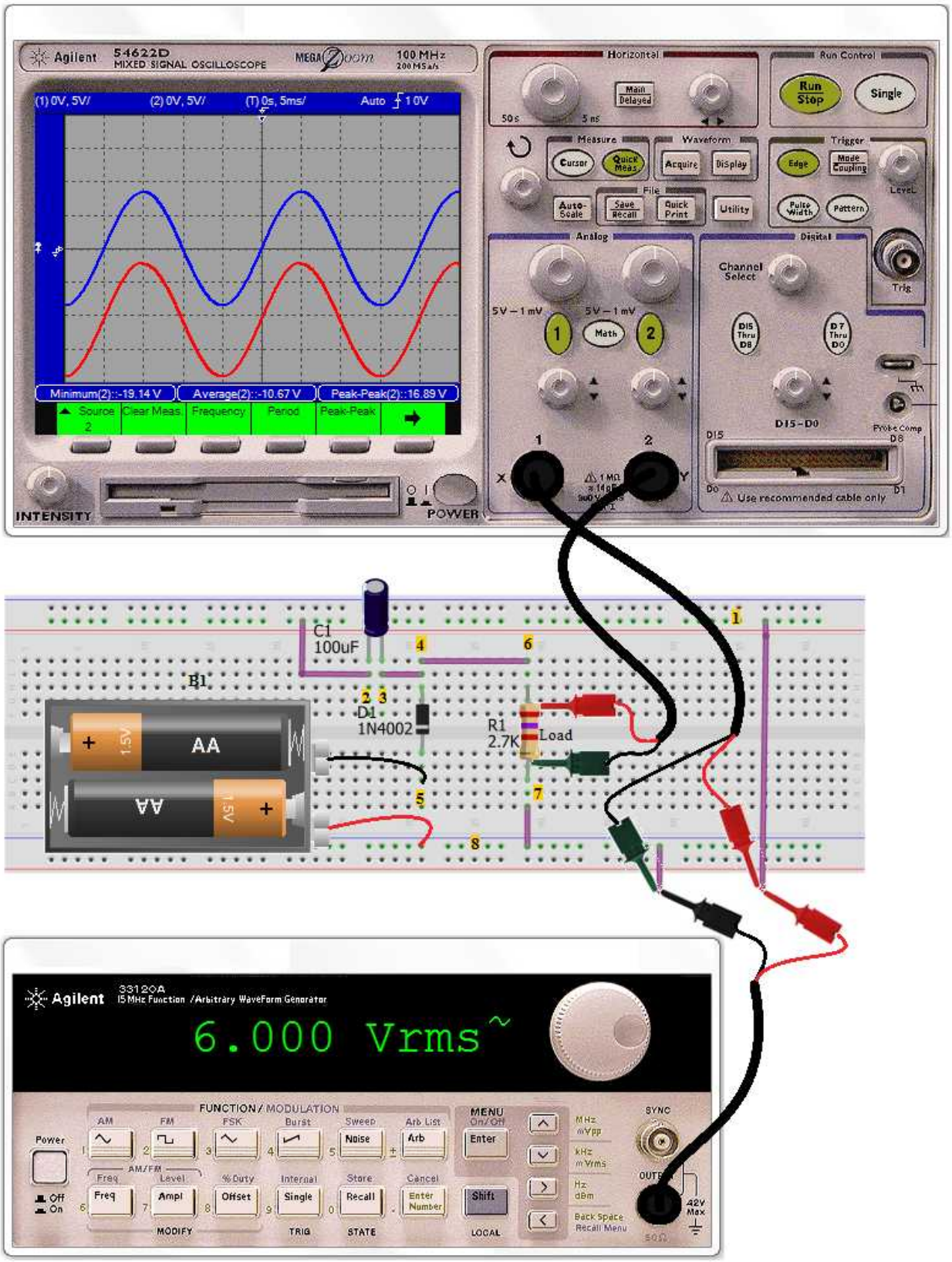


Figure 9-10: Biased negative clamper, real world circuit connection

9. 4. Applications of clamping circuits

Clamping circuits are used to shift any part of the input signal waveform and can be maintained at a specified voltage level. Such circuits are used in analog television receivers to restore the original d.c reference signal (corresponding to the brightness level of the picture) to the video signal. Analog television have a DC restorer circuit, which returns the voltage of the signal during the back porch of the line blanking period to 0 V. Low frequency interference, especially power line hum, induced onto the signal spoils the rendering of the image, and in extreme cases causes the set to lose synchronization. This interference can be effectively removed by using clamping circuits. In other words, the signal that is sent to the TV receiver may lose the dc components after being passed through capacitive coupled amplifiers. Thus the signal loses its black and white reference levels and the blanking level. Before passing these signals to the picture tube, these reference levels have to be restored. This is done by using clamper circuits. Though the dc component that is lost in transmission is not the same as that introduced through a clamping circuit, the necessity to establish the extremity of the positive or negative signal excursion at some reference level is important.

Clamper circuits also find their application in both television transmitters and receivers where are used as a “DC restorer” in “composite video” circuitry. An NTSC (US video standard) video signal “white level” corresponds to minimum (12.5%) transmitted power. The video “black level” corresponds to a high level (75% of transmitter power. There is a “blacker than black level” corresponding to 100% transmitted power assigned to synchronization signals. The NTSC signal contains both video and synchronization pulses. The problem with the composite video is that its average DC level varies with the scene, dark versus light. The video itself is supposed to vary. However, the sync must always peak at 100%. To prevent the sync signals from drifting with changing scenes, a “DC restorer” clamps the top of the sync pulses to a voltage corresponding to 100% transmitter modulation.

Clamper circuits are also used in storage counters, analog frequency meter, capacitance meter, divider and stair-case waveform generator.

Chapter ten

Voltage Multiplier

Objectives

When you have studied this chapter, you should

- Have an understanding of the working principle of the voltage multipliers
- Be aware of the nuisance while working with high dc voltage
- Be capable to design any type of voltage multiplier for any required voltage
- Have an understanding of the applications of the diodes and capacitor voltage multipliers

Further reading
Study aids for this chapter are available at
Zumbahlen, Hank (2008), *Linear Circuit Design Handbook*, Newnes

A voltage multiplier is a special type of diode rectifier circuit which produces an output voltage greater than of the applied AC input voltage. The produced output voltage is theoretically an integer times the AC peak input, for example, 2, 3, 4, 5 etc. times the AC peak input. This type of voltage multiplier generates high voltages at relatively low currents and the circuit is generally at low cost. The circuit is constructed based on diodes and capacitor cascaded in concordance of the required output voltage. The diode and capacitor voltage multiplier is also referred to as Cockcroft Walton multiplier, named after the two men who used this circuit design to be the first to succeed in performing the first nuclear disintegration in 1932. James Douglas Cockcroft and Ernest Thomas Sinton Walton, in fact have used this voltage multiplier cascade for the research which later made them winners of the 1951 Nobel Prize in physics for "Transmutation of atomic nucleus by artificially accelerated atomic particles". Less known is the fact that the circuit was first discovered much earlier, in 1919, by Heinrich Greinacher, a Swiss physicist. For this reason, this doubler cascade is sometimes also referred to as the Greinacher multiplier.

10. 1. Diode and capacitor voltage multiplier

Although it is usual in Electronic circuits to use a voltage transformer to increase a voltage, sometimes a suitable step-up transformer or a specially insulated transformer required for high voltage applications may not always be available. One alternative approach is to use a diode voltage multiplier circuit which increases or "steps-up" the voltage without the use of a transformer. Unlike transformers this method eliminates the requirement for the heavy core and the bulk of insulation or potting required. By using only capacitors and diodes, these voltage multipliers can step up relatively low voltages to extremely high values, while at the same time being far lighter and cheaper than transformers. The major advantage of such circuit is that the voltage across each stage of this cascade is only equal to twice the peak input voltage, so it has the advantage of requiring relatively low cost components and being easy to insulate.

Within a power supply or other rectifier circuit it is possible to configure the diodes in such a way that they double, triple or more, the level of the incoming voltage. Thus, it is possible to get 20 V_{DC} from a 10 Vpeak AC source using a doubler, 40 V_{DC} from a quadrupler. Any load in a practical circuit will lower these voltages. This type of voltage multiplier circuit finds uses in many applications where a low current, high voltage source is required.

10. 2. Voltage Doubler

As its name imply, a Voltage Doubler is a voltage multiplier circuit which has a voltage multiplication factor of two. The circuit consists of only two diodes, two capacitors and an oscillating AC input voltage (a Pulse Width Modulation waveform could also be used). This simple diode-capacitor pump circuit gives a DC output voltage equal to the peak-to-peak value of the sinusoidal input. In other words, double the peak voltage value because the diodes and the capacitors work together to effectively double the voltage.

- **Half wave voltage doubler**

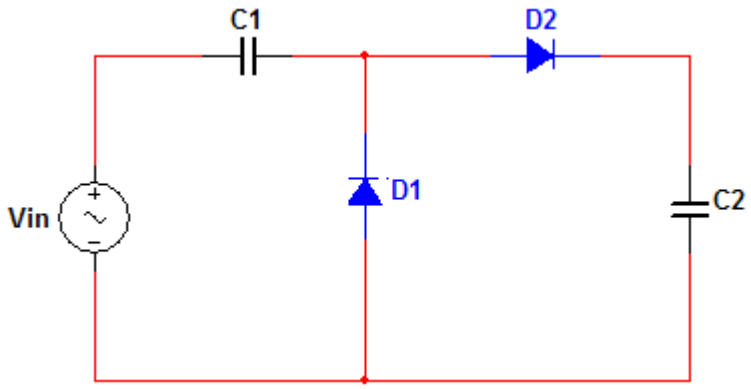


Figure 10-1: Half wave voltage doubler circuit principle

The half-wave voltage doubler is composed of two circuits: clamper and peak-detector (half-wave rectifier).

The peak detector (half wave rectifier) in figure 10-2 part (b) is shown in modified form where capacitor C_1 has been added. Referring to the above circuit (a), capacitor C_1 charges to the peak voltage of the supply, $V_{C1}=V_{in}*\sqrt{2}$,($V_{C1}=(V_{in}*\sqrt{2})-07$ considering the diode drop), on the negative

half cycle of AC input. The right end is grounded by the conducting of D_1. The left end is charged at the negative peak of the AC input. This has the same operation of the clamper.

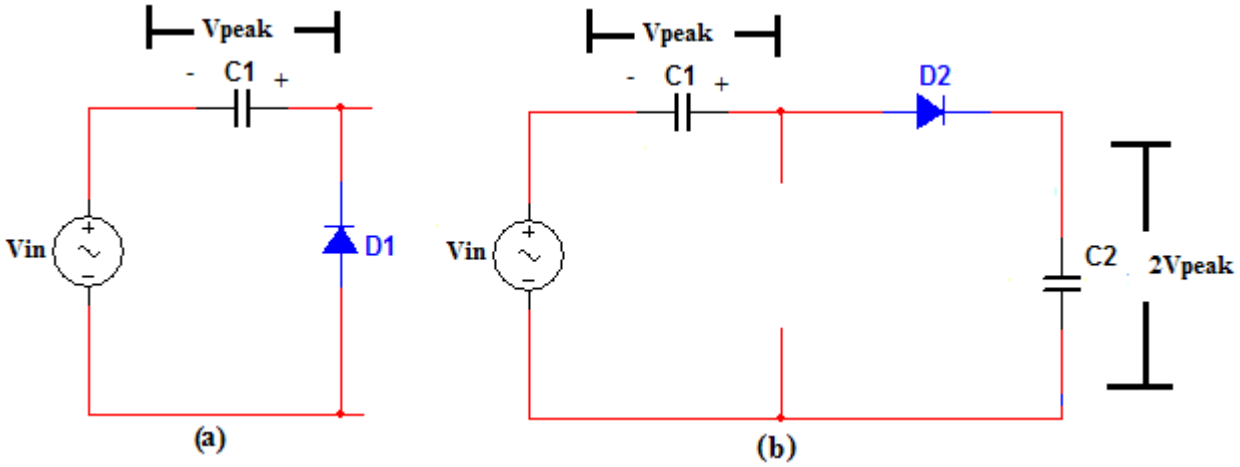


Figure 10-2: Voltage doubler; (a) Clamper and peak-detector, (b) Half-wave rectifier

During the positive half cycle, the half wave rectifier comes into play at figure 10-2 part (b). Diode D_1 is out of the circuit since it is reverse biased. Capacitor C_1 is now in series with the voltage source. At this time the polarities of the generator and capacitor C_1 becomes in series aiding. Thus, rectifying diode D_2 sees a total voltage at the peak of the sine wave, $V_{in}*\sqrt{2}$ from generator and $V_{C1} = V_{in}*\sqrt{2}$ from capacitor C_1. This total voltage charges the capacitor C_2 with $V_{C2} = 2* V_{in}*\sqrt{2}$ ($V_{in}*\sqrt{2} - (V_{in}*\sqrt{2}) - 0.7$ inconsideration of diode voltage drop).

In other words, V(positive peak) + V(negative peak) as on the negative half-cycle, D_1 charges C_1 to peak and on the positive half cycle D_2 adds the AC peak voltage to V_{peak} on C_1 and transfers it all to C_2. The voltage across capacitor C_2 discharges through the load ready for the next half cycle.

Then the voltage across capacitor, C_2 can be calculated as:

$$V_{out} = 2V_p, \text{ (minus of course the voltage drops across the diodes used)}$$

Where Vp: The peak value of the input voltage.

Note that this double output voltage is not instantaneous but increases slowly on each input cycle, eventually settling to $2V_p$. As capacitor C_2 only charges up during one half cycle of the input waveform, the resulting output voltage discharged into the load has a ripple frequency equal to the supply frequency, hence the name half wave voltage doubler.

The disadvantage is the difficulty to smooth out this large ripple frequency almost the same way as for a half wave rectifier circuit. Also, capacitor C_2 must have a DC voltage rating at least twice the value of the peak input voltage.

- **Full wave voltage doubler**

Full wave voltage doubler circuit is made up from two half-wave rectifier circuits. This is achieved by adding a second diode and capacitor to the output of a standard half wave rectifier and this helps to increase its output voltage to the double of the input.

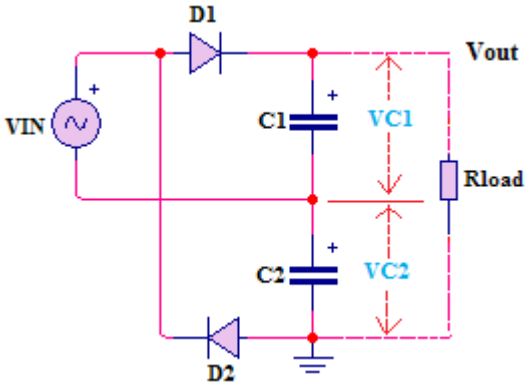


Figure 10-3: Full wave voltage doubler circuit principle

Working Principle of the Circuit

For the positive half cycle of the input voltage V_{in}, capacitor C_1 charges up to (V_{C1}) the peak of the applied input voltage through diode D_1. When the sinusoidal input voltage V_{in} is negative, capacitor C_2 charges up to (V_{C2}) the peak input through diode D_2. These two capacitors work as storing devices (batteries) with series adding. Therefore the output voltage Vout is summation of voltage stored by two capacitors, $V_{out} = V_{C1}+V_{C2} = 2V_{in(peak)}$ and is taken across the two series connected capacitors. The advantage of such circuit is an easy smoothing.

Experiment 10-1: Half wave voltage doubler and full wave voltage doubler

Design a voltage multiplier based on voltage doubler capable to provide output DC voltage double of the input AC voltage from $9V_{AC}$ supply. Use components with specification described in the part list below and measure the resulting voltage using voltmeter.

Part list

No	Items	Specifications	Quantity
1	9VAC supply	Agilent function generator 33120A	1
2	Voltmeter	Digital multimeter	1
3	Breadboard	Prototyping board (mini board)	1
4	Connecting wire	22-gauge (0.33mm^2) solid wire	20cm
5	Diode (D1 and D2)	1N4007	2
6	Capacitor (C1 and C2)	33µF/50V electrolytic Capacitor	2
7	Load resistor	10KΩ, ½ watt	1

- **Half wave voltage doubler**

Let consider the half wave voltage doubler of the circuit figure 10-4 obtained by assigning the values to the prior detailed circuit with the above items specifications.

Procedure and Working Principle

The circuit, figure 10-4, shows a half wave voltage doubler. During the negative half cycle of the

sinusoidal input waveform V_{in}, diode D_1 is forward biased and conducts charging up the capacitor C_1 to the peak value (V_p) of the input voltage.

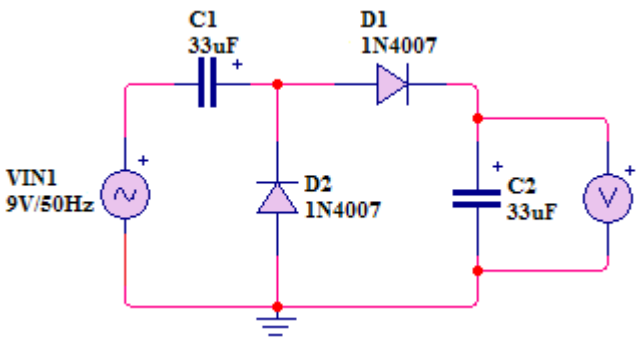


Figure 10-4: Half wave voltage doubler circuit

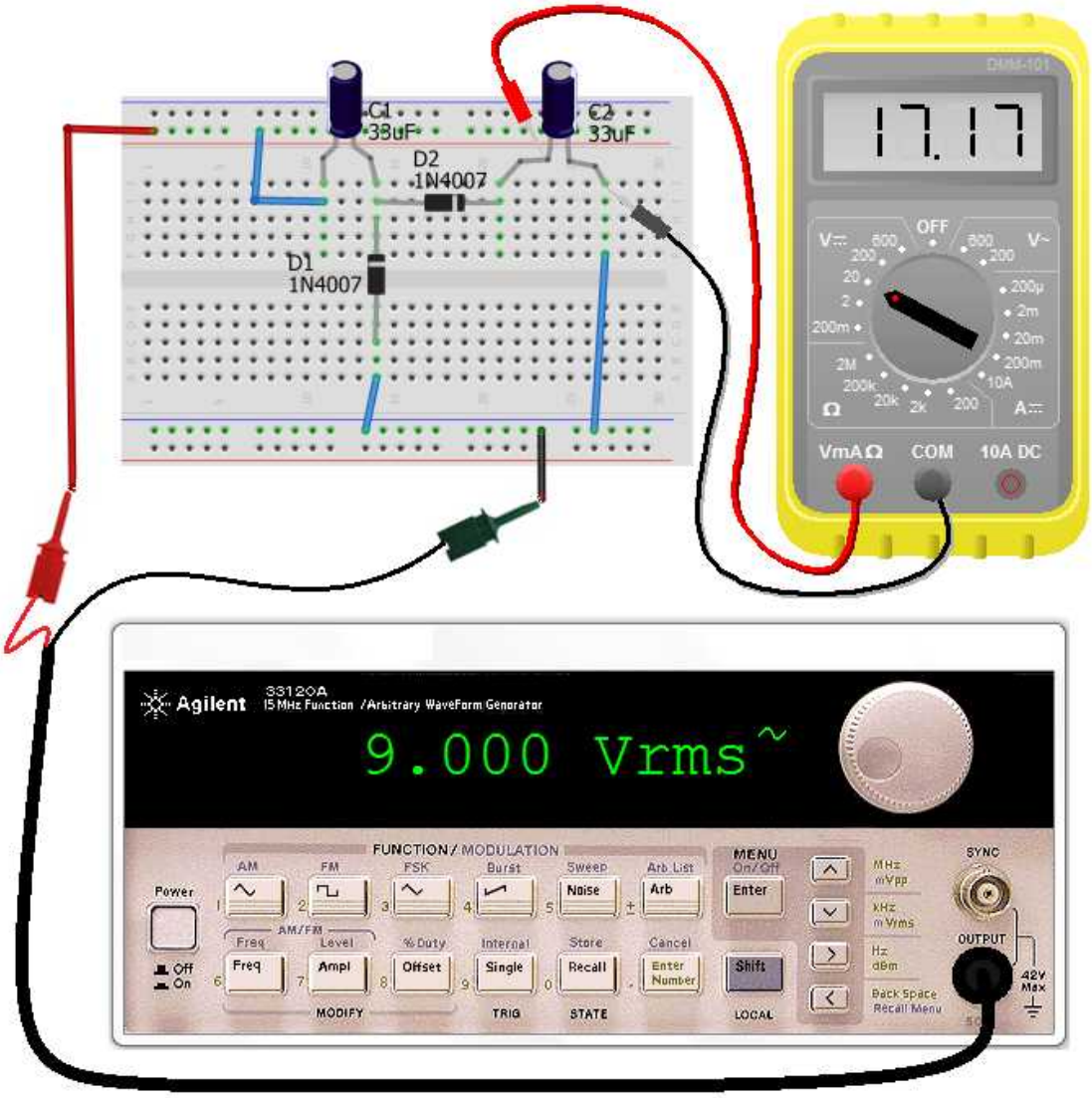


Figure 10-5: Half wave voltage doubler, real world circuit connection

$V_{C1} = V_{in} * \sqrt{2} = 9V * 1.4142 = 12.7279V$; (12.0279 V considering the diode drop). Because there is no path for capacitor C_1 to discharge into, it remains fully charged and acts as a battery in series with the voltage supply V_{in}.

During the positive half cycle, diode D_1 is reverse biased blocking the discharging of C_1 while diode D_2 is forward biased charging up capacitor C_2. Since there is a voltage across capacitor C_1 already equal to the peak input voltage 12.7279V (12.0279V considering diode drop), capacitor C_2 charges to twice the peak voltage value of the input signal V_{in} or simply say $V_{(positive\ peak)} + V_{(negative\ peak)}$.

$$V_{C2} = 2 * V_{in} * \sqrt{2}$$
$$= 2 * 9 * 1.4142$$
$$= 25.4558V;\ (25.4558V - 1.4V = 24.0558V \text{ considering diodes voltage drops.}$$

Voltmeter reading is rms value and this is given by:

$$V_{rms} = V_{peak} / \sqrt{2}$$
$$= 24.0558 / 1.4142 = 17.01V$$

- **Full wave voltage doubler**

The full-wave voltage doubler is composed of a pair of series stacked half wave rectifiers as shown in the circuit figure 10-6.

The bottom rectifier charges C_2 on the negative half cycle of input. The top rectifier charges C_1 on the positive half cycle. Each capacitor takes on a charge the peak voltage of the supply, that is 9* V or 12.727V (12.0.27V considering diode drop). The output voltage is the series total voltage stored in capacitor C_1 and C_2.

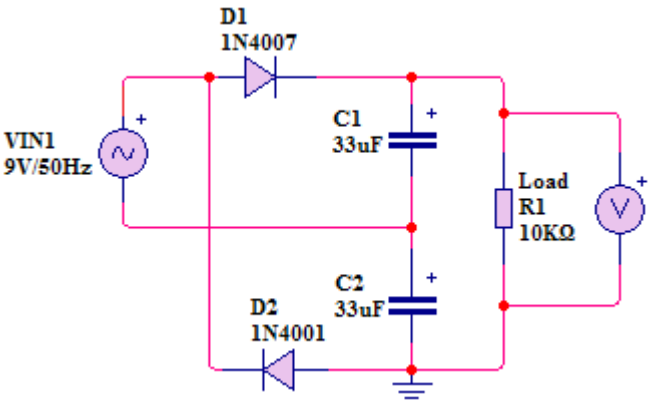


Figure 10-6: Full wave voltage doubler circuit

$V_{out} = V_{C1} + V_{C2} = 12.727\ V + 12.727\ V = 25.456\ V$;

$V_{out} = 12.027V * 2 = 24.054\ V$ (by considering diode drops).

Voltmeter reading is rms value and this is given by:

$V_{rms} = V_{peak} / \sqrt{2} = 24.054\ V / 1.4142 = 17.008\ V$

Safety point

Be careful when touching or handling capacitors in or out of a circuit. Capacitors are capable of storing electrical charge for a long time after power has turned off in a circuit. If you touch the leads, you may be in for a shock as the capacitor discharges through you! It is usually good practice to discharge a capacitor using a shorting tool with an insulated grip of some sort before handling the capacitor.

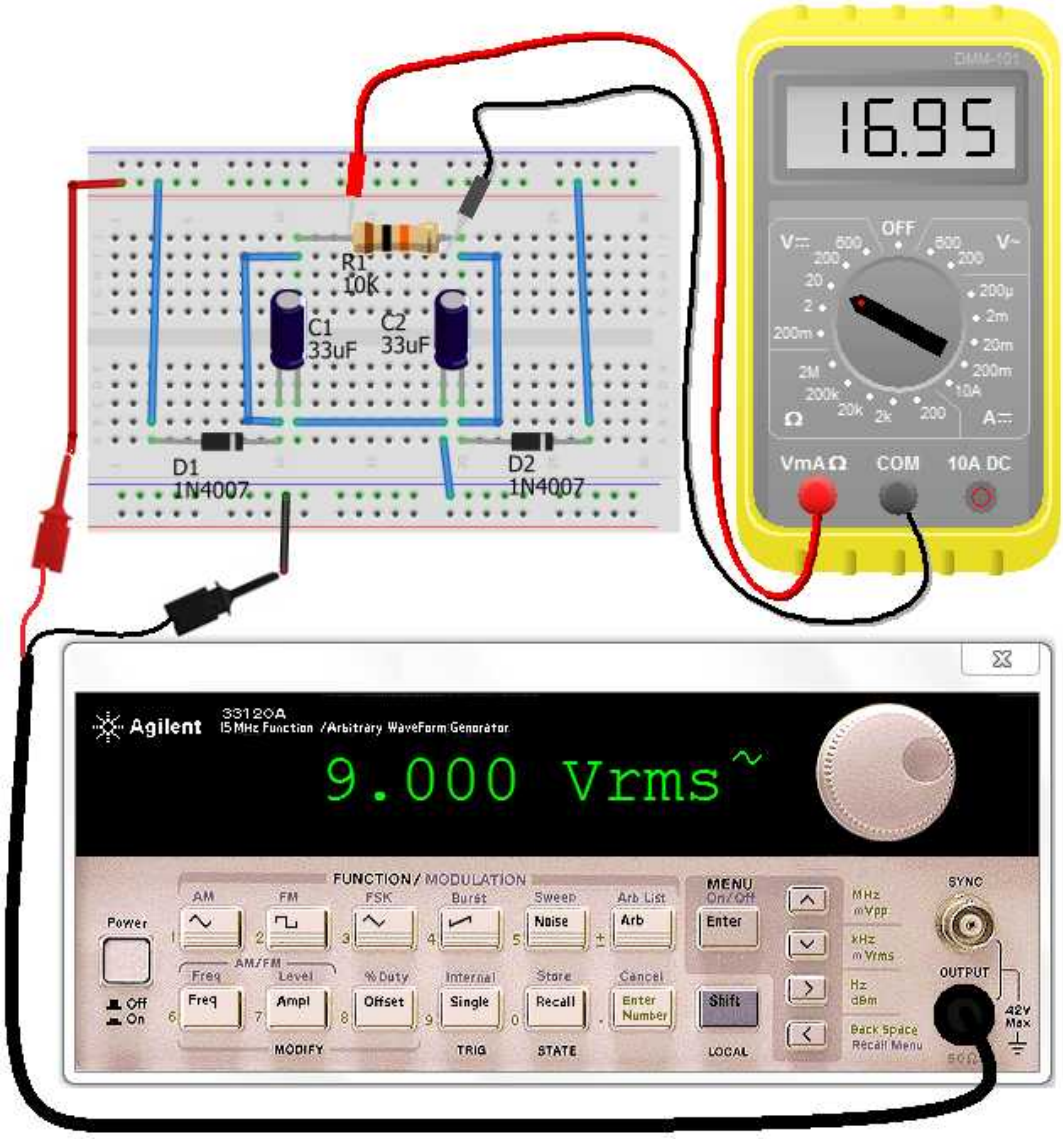


Figure 10-7: Full wave voltage doubler, real world circuit connection

10. 3. Voltage tripler

Voltage tripler is a diode-capacitor circuit that is able to provide output voltage three times of the input voltage.

- **Half wave voltage tripler**

Half wave voltage tripler is constructed by adding an additional single diode-capacitor stage to the half-wave voltage doubler circuit and this increases its input voltage by a factor of three where the name Voltage Tripler Circuit.

These voltage multiplier circuits give a DC output equal to three times the peak voltage value ($3V_p$) of the sinusoidal input signal. As with the previous voltage doubler, the diodes within the voltage tripler circuits charge and block the discharge of the capacitors depending upon the direction of the input half-cycle. Then $1V_p$ is dropped across C_3 and $2V_p$ across C_2 and as the two ca-

pacitors are in series and act as batteries, this results in the output load seeing a voltage equivalent to $3V_p$.

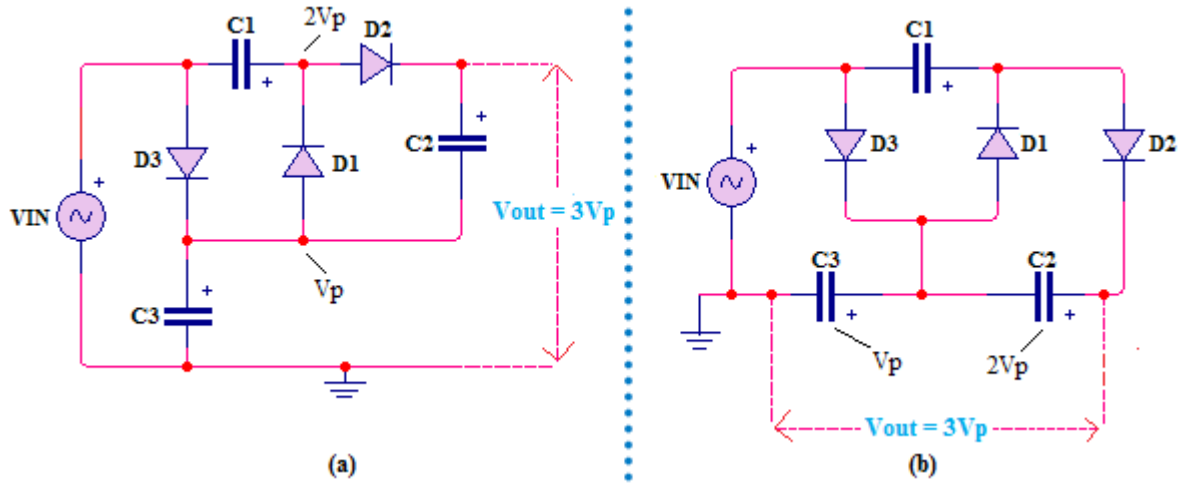


Figure 10-8: (a) and (b), Half wave voltage tripler base circuits

- **Full wave voltage tripler**

A full wave voltage tripler is built from a combination of a doubler and a half wave rectifier (C_3, D_3). The half-wave rectifier produces the peak voltage from input, $V_p=V_{in}*\sqrt{2}V$, ($V_p=V_{in}*\sqrt{2}V-0.7V$ considering diode drop) at node junction of C_3 and C_2.

The doubler provides another $2V_p=2*V_{in}*\sqrt{2}V$ ($2*V_{in}*\sqrt{2}V-1.4V$ considering diode voltage drop) at the terminal of C_2. For a total output voltage of $3V_p=3V_{in}*\sqrt{2}V$ ($3V_{in}*\sqrt{2}V-2.1V$ considering diode voltage drop) at the output of D_2 with respect to ground.

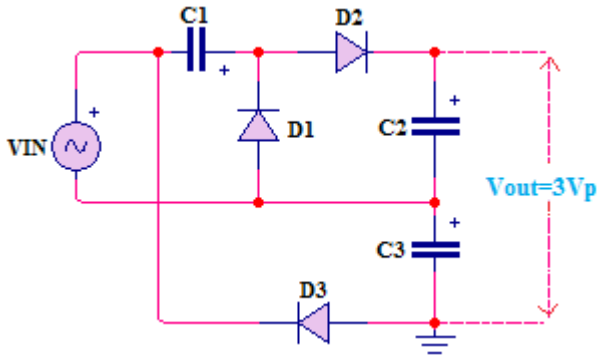


Figure 10-9: Full wave voltage tripler circuit principle

Experiment 10-2: Halfwave voltage tripler, fullwave voltage tripler

Design a voltage multiplier based on voltage tripler capable to provide output DC voltage three times the input AC voltage from 9VAC supply. Use components with specification described in the part list below and measure the resulting voltage using voltmeter.

Part list

No	Items	Specifications	Quantity
1	9VAC supply	Agilent function generator 33120A	1
2	Voltmeter	Digital multimeter	1
3	Breadboard	Prototyping board (RSR 03MB102)	1
4	Connecting wire	22-gauge (0.33mm^2) solid wire	20cm
5	Diode (D1,D2 and D3)	1N4002	3
6	Capacitor (C1, C2 and C3)	47µF/100V electrolytic Capacitor	3
7	Load resistor	100KΩ, 1watt	1

- **Half wave voltage tripler**

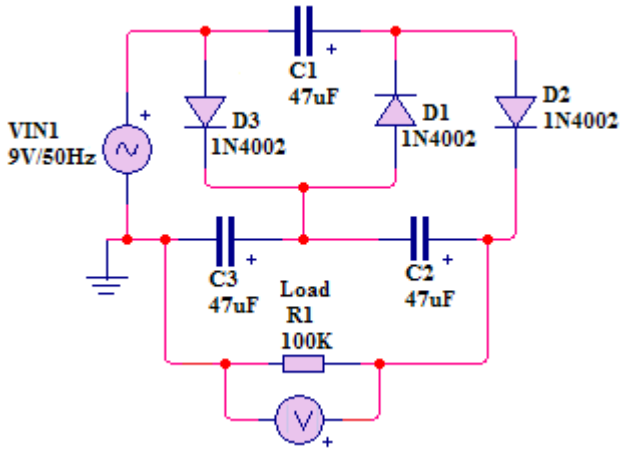


Figure 10-10: Half wave voltage tripler circuit

Procedure and Working Principle

1. Positive half cycle of the input voltage V_{in}, capacitor C_3 is charged through D_3 to the peak value $V_p = 9V*\sqrt{2}$, that is 12.7278 V (12.0278 V considering diode voltage drop) between left and right plate of the capacitor C_3.
2. Negative half cycle of the supply voltage V_{in}, the potential of C_3 (V_{C3}) adds with that of supply V_{in} thus charging capacitor C_1 through D_1 to $2V_p = 9*\sqrt{2}+9*\sqrt{2}$, that is 25.4556V (24.0556V considering diode voltage drop).
3. Positive half cycle of the input supply V_{in}, the potential of C_3 (V_{C3}) has dropped to 0V thus allowing capacitor C_2 to be charged to $3V_p$ through D_2, the potential of C_1 (V_{C1}) adds to the source V_{in}.

$$V_{C2} = 3V_p = 9V*\sqrt{2} + 2*9V*\sqrt{2}$$
$$= 12.7278V + 25.4556V = 38.1834\ V\ (36.0834\ V \text{ considering diodes voltage drop})$$

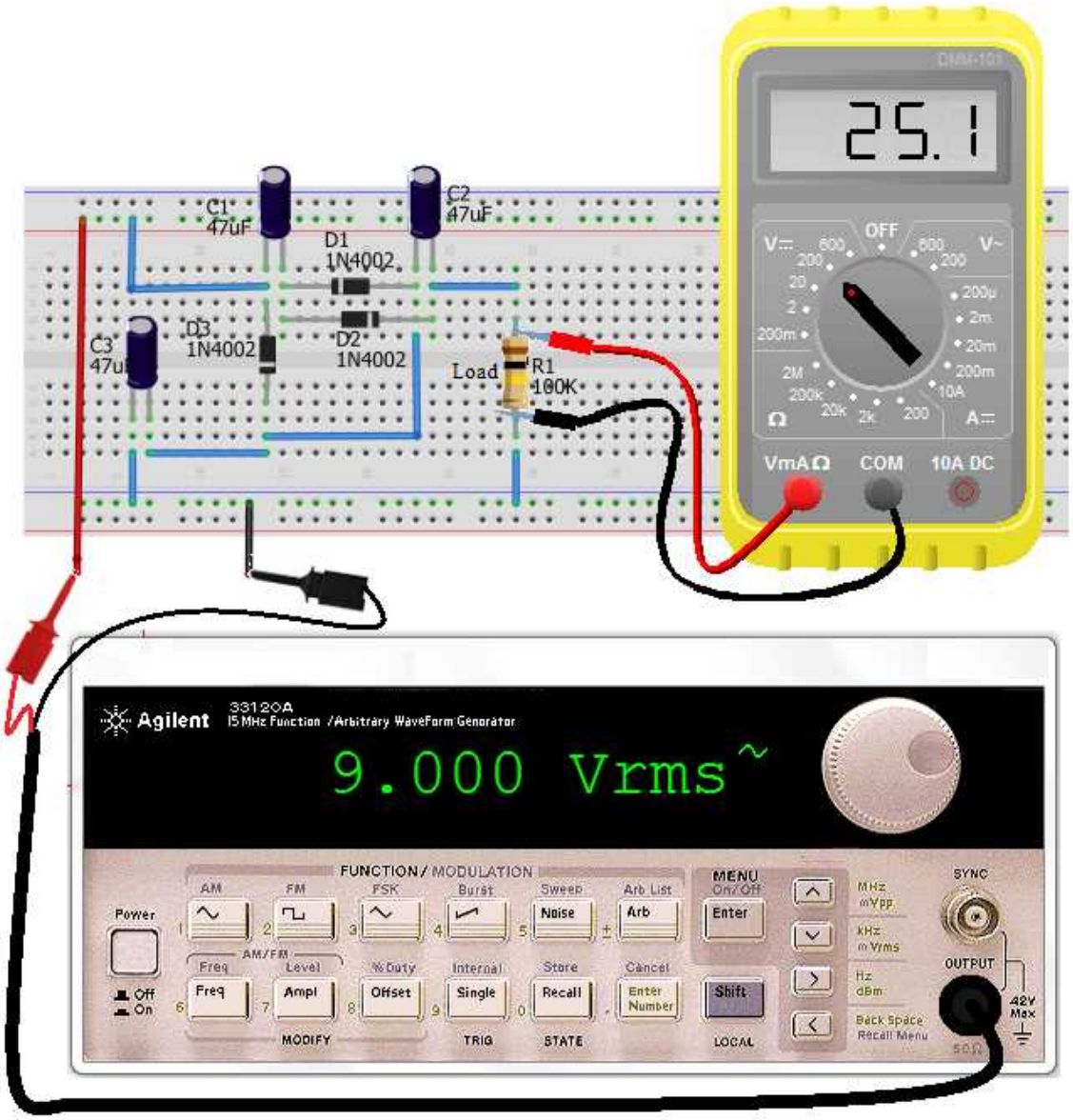


Figure 10-11: Half wave voltage tripler, real world circuit connection

- **Full wave Voltage Tripler**

Procedure and Working Principle

1. Negative half cycle of the input voltage V_{in}, capacitor C_1 is charged through D_1 to the peak value V_p=9V*√2, that is 12.7278V (12.0278V considering diode voltage drop) between left and right plate of the capacitor C_1. At the same time, capacitor C_3 charges to the peak value V_{C3}=12.7278V (12.0278V considering diode drop)
2. Positive half cycle of the supply voltage V_{in}, the potential of C_1 (V_{C1}) adds with that of supply V_{in} thus charging capacitor C_2 through D_2 to $2V_p$=9*√2+9*√2 , that is 25.4556V (24.0556V considering diode voltage drop).

Thus the potential of capacitor C_2 (V_{C2}) adds to that of capacitor C_3 (V_{C3}) to give output voltage that is equal to $3V_p$.

$V_{out}=V_{R(load)}=3*9V*\sqrt{2}=38.1834V$ (36.0834V considering diodes drop)

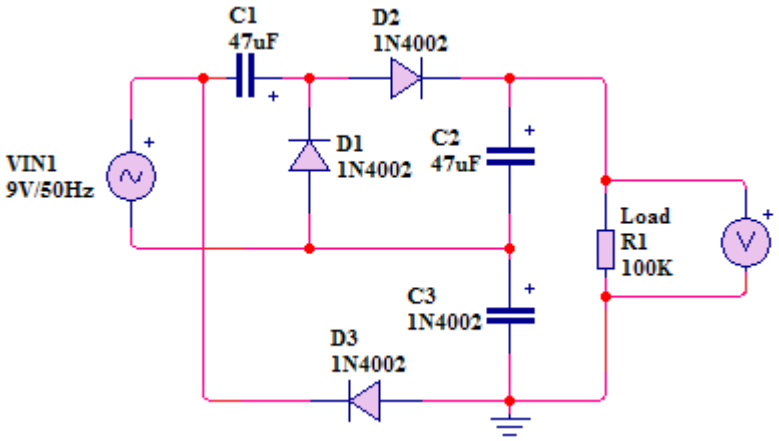


Figure 10-12: Full wave voltage tripler circuit

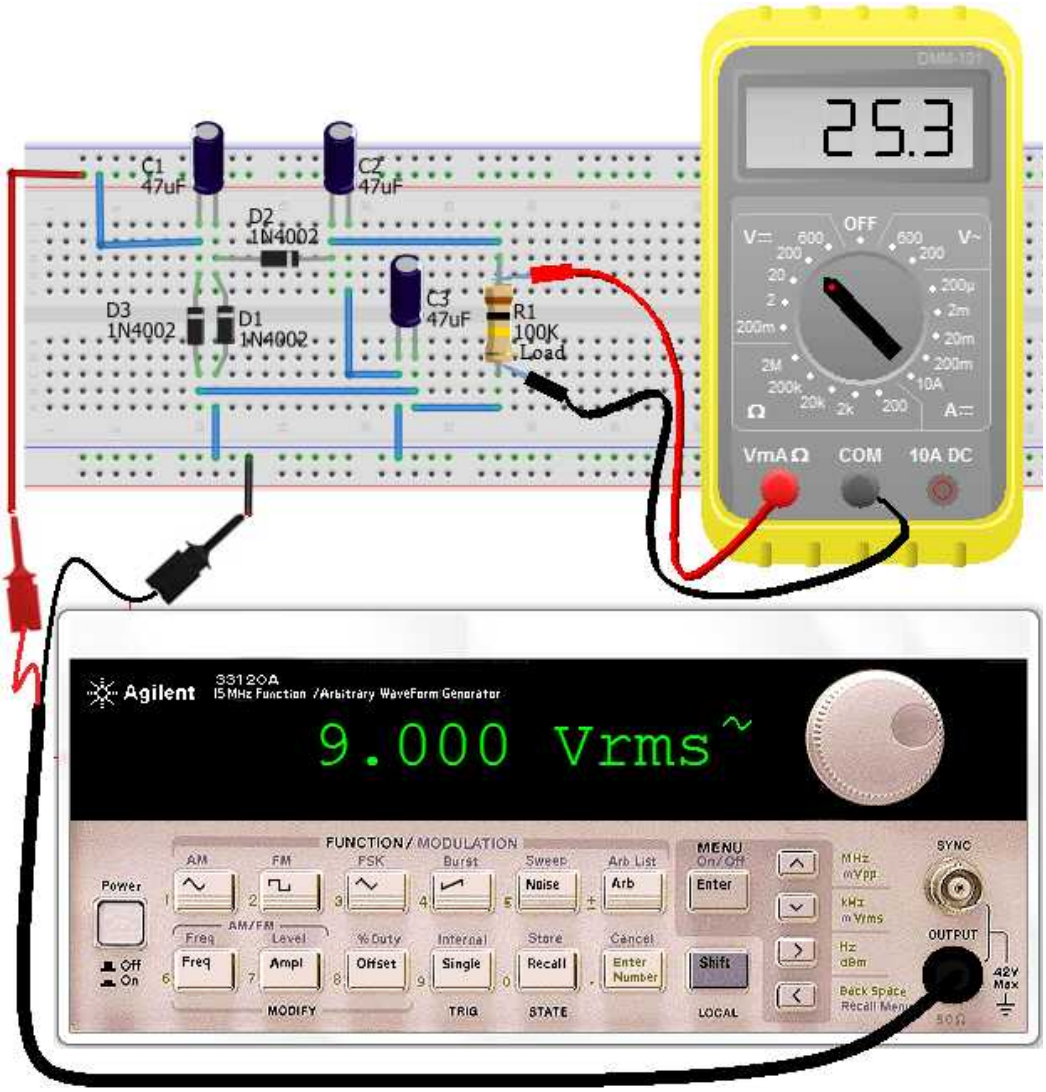


Figure 10-13: Full wave voltage tripler, real world circuit connection

PVariations of the basic circuit and concept are available to provide a voltage multiplier function of almost any factor. Applying the same principle of sitting one rectifier on top of another and using capacitive coupling enables a form of ladder network to build up.

To calculate the expected voltage at the output with a given input and number of stages, just replace number in the following formula:

$$V_{out}=(2xV_{in})xSx\sqrt{2}$$

Where

V_{out}: The output voltage,

V_{in}: Input voltage from supply and

S: The number of stages

In theory any desired amount of voltage multiplication can be obtained and a cascade of "N" doublers, would produce an output voltage of 2N.Vp volts. For example, a 10-stage voltage multiplier circuit with a peak input voltage of 100 volts would give a DC output voltage of about 1,000 volts or 1kV, assuming no losses, without the use of a transformer. This is achieved by simply using circuits made from diodes and capacitors that can increase the input voltage by two, three, or four times, etc, depending on the ratio of the output voltage to the input voltage, by cascading together individual half or full stage multipliers in series to apply the desired DC voltage to a given load without the need for a step-up transformer.

However, the diodes and capacitors used in all multiplication circuits need to have a minimum reverse breakdown voltage rating of at least twice the peak voltage across them as multi-stage voltage multiplication circuits can produce very high voltages, so take care. Also, voltage multipliers usually supply low currents to a high resistance loads as the output voltage quickly drops away as the load current increases.

10. 4. Positive and negative voltage multiplier

The Voltage Multiplication circuits shown above are all designed to give a positive DC output voltage. But they can also be designed to give negative voltage outputs by simply reversing the polarities of all the multiplier diodes and capacitors to produce negative voltage doublers.

Several cycles are required to reach full voltage. The polarity of the high voltage output is simply determined by the configuration of the diodes, as shown in the diagrams above.

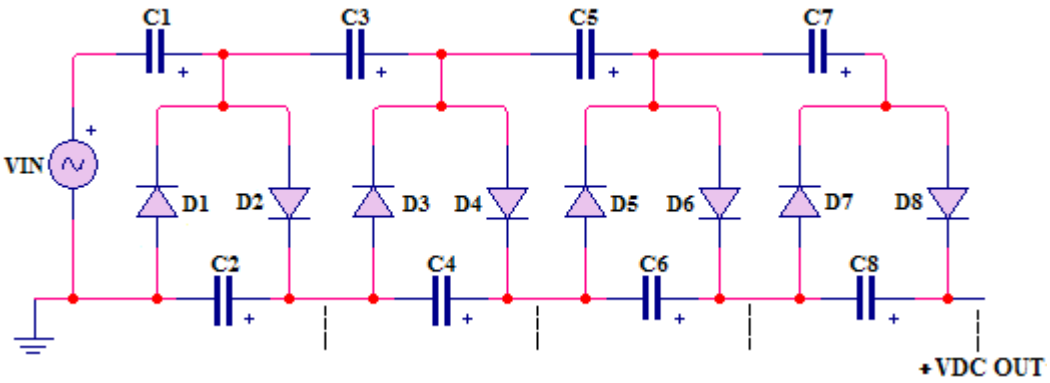


Figure 10-14: Positive multiplier circuit principle

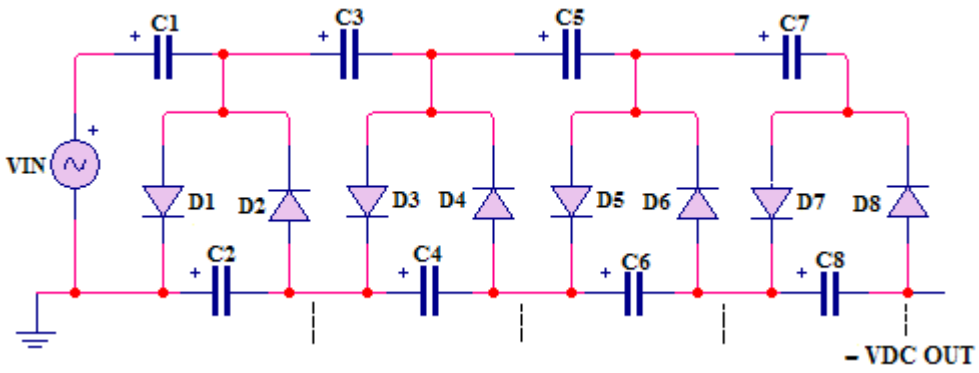


Figure 10-15: Negative multiplier circuit principle

In any multiplier running under load the average DC current flowing through each diode, I_{diode}, is the same.

In reality, more cycles are required to reach the full voltage as shown in the figure 10-16.

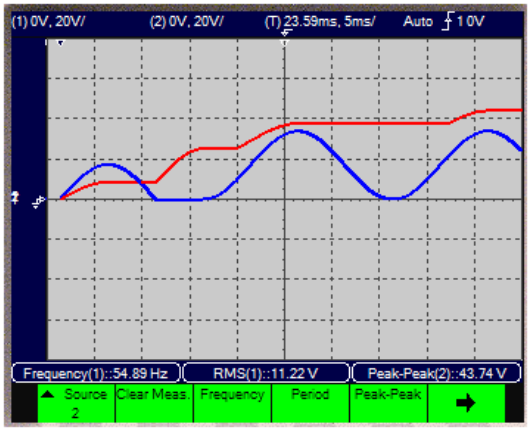


Figure 10-16: Cycles to reach to the full voltage

10. 5. Full wave voltage multipliers circuit principle

Increasing the frequency can dramatically reduce the ripple, and the voltage drop under load, which accounts for the popularity of driving a multiplier stack with a switching power supply. A clever way to reduce ripple is to implement a full wave voltage doubler as shown in figure 10-17. This effectively doubles the number of charging cycles per second, and thus cuts down the voltage drop and ripple factor. The input is usually fed from a centre tapped ac transformer or MOSFET H-bridge circuits.

The Cockcroft Walton or Greinacher design is based on the Half-Wave Series Multiplier, or voltage doubler. In fact, all multiplier circuits can be derived from its operating principles.

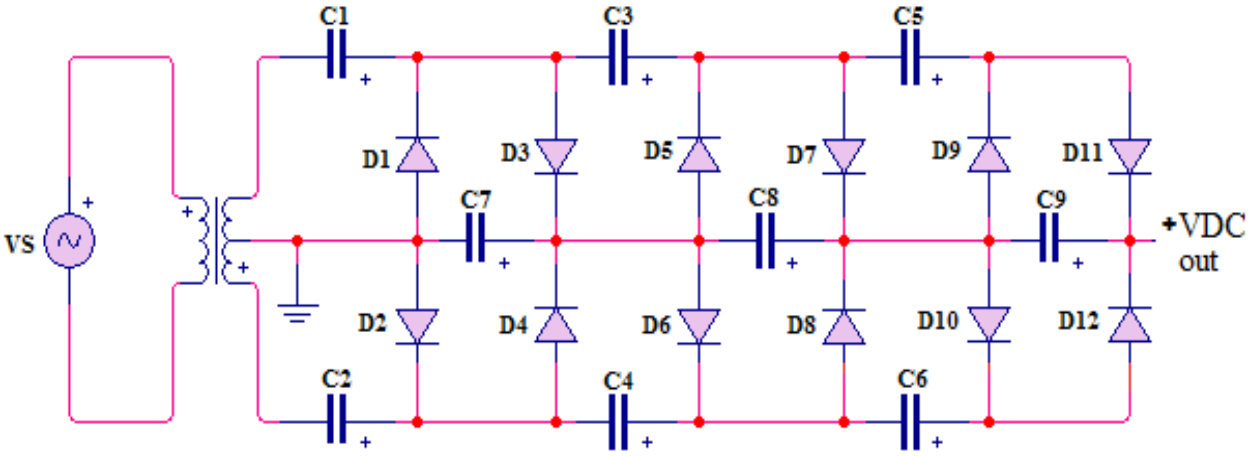


Figure 10-17: Full wave voltage multiplier circuit principle

10. 6. Precautions

Voltage multipliers produce lethal current at high voltage. The output of these devices can cause injury which can result in death if the common sense safety procedures are not followed.

Safety precautions and procedures

- Wear rubber safety groves and stand on a rubber safety mat when powering or using voltage multipliers.
- Ground the output of voltage multiplier after powering it off. It can retain a lethal voltage for several minutes after powering down.
- Do not touch any of its device at any time during operation
- Do not allow others who are not familiar with high voltage devices to touch or use without proper supervision.
- Do not operate these devices alone. Have an emergency person available when performing your experiment who is familiar with proper rescue procedures.

10. 7. Applications of voltage multipliers

The voltage multiplier circuits are very useful. However they are normally suitable only for low current applications. As the voltage multiplication increases the losses increase. The source resistance tends to rise, and loading becomes an issue. For each diode in the chain there is the usual diode drop (normally 0.6 volts for a silicon diode), but the reactance of the capacitors can become significant, especially when mains frequencies of 50 or 60 Hz are used. High voltage high value capacitors can be expensive and large. This may provide physical constraints for making them too large. Voltage multipliers have many practical applications and find their way in laser systems, CRT tubes, hv power supplies, LCD backlighting, power supplies, x-ray systems, traveling wave tubes, ion pumps, electrostatic systems, air ionisers, particle accelerators, copy machines, scientific instrumentation, oscilloscopes, and many other applications that utilize high voltage DC.

Devices Datasheets

Appendix

1N4001, 1N4002, 1N4003, 1N4004, 1N4005, 1N4006, 1N4007

Vishay General Semiconductor

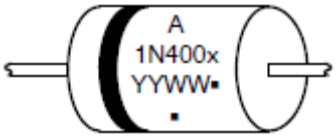
General Purpose Plastic Rectifier

This data sheet provides information on subminiature size, axial lead mounted rectifiers for general−purpose low−power applications.

CASE: DO-41

DO-204AL (DO-41)

MARKING



A = Assembly Location

1N400x = Device Number

x = 1, 2, 3, 4, 5, 6 or 7

YY = Year

WW = Work Week

▪ = Pb−Free Package

(Note: Microdot may be in either location)

PRIMARY CHARACTERISTICS	
$I_{F(AV)}$	1.0 A
V_{RRM}	50 V to 1000 V
I_{FSM} (8.3 ms sine-wave)	30 A
I_{FSM} (square wave t_p = 1 ms)	45 A
V_F	1.1 V
I_R	5.0 µA
T_J max.	150 °C

FEATURES

- Low forward voltage drop
- Low leakage current
- High forward surge capability
- Solder dip 275 °C max. 10 s, per JESD 22-B106
- Compliant to RoHS Directive 2002/95/EC and in accordance to WEEE 2002/96/EC

TYPICAL APPLICATIONS

For use in general purpose rectification of power supplies,

inverters, converters and freewheeling diodes application.

MECHANICAL DATA

Case: DO-204AL, molded epoxy body

Molding compound meets UL 94 V-0 flammability rating

Base P/N-E3 - RoHS compliant, commercial grade

Terminals: Matte tin plated leads, solderable per

J-STD-002 and JESD 22-B102

E3 suffix meets JESD 201 class 1A whisker test

Polarity: Color band denotes cathode end

MAXIMUM RATINGS (T_A = 25 °C unless otherwise noted)									
PARAMETER		SYMBOL	IN4001	IN4002	IN4003	IN4004	IN4005	IN4006	IN4007	UNIT
Maximum repetitive peak reverse voltage		V_{RRM}	50	100	200	400	600	800	1000	V
Maximum RMS voltage		V_{RMS}	35	70	140	280	420	560	700	V
Maximum DC blocking voltage		V_{DC}	50	100	200	400	600	800	1000	V
Maximum average forward rectified current 0.375" (9.5 mm) lead length at T_A = 75 °C		$I_{F(AV)}$	1.0							A
Peak forward surge current 8.3 ms single half sine-wave superimposed on rated load		I_{FSM}	30							A
Non-repetitive peak forward surge current square waveform T_A = 25 °C	t_p=1ms	I_{FSM}	45							A
	t_p=2ms		35							
	t_p=5ms		30							
Maximum full load reverse current, full cycle average 0.375" (9.5 mm) lead length T_L = 75 °C		**$I_{R(AV)}$**	**30**							**µA**
Rating for fusing (t < 8.3 ms)		**I^2t(1)**	**3.7**							**A^2S**
Operating junction and storage temperature range		**T_J, T_{STG}**	**-50 to +150**							**°C**

Note

(1) For device using on bridge rectifier application

Stresses exceeding Maximum Ratings may damage the device. Maximum Ratings are stress ratings only. Functional operation above the Recommended Operating Conditions is not implied. Extended exposure to stresses above the Recommended Operating Conditions may affect device reliability.

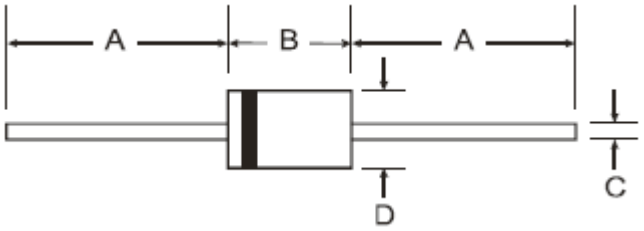
ELECTRICAL CHARACTERISTICS (T_A = 25 °C unless otherwise noted)										
PARAMETER	**TEST CONDITIONS**	**SYMBOL**	**1N4001**	**1N4002**	**1N4003**	**1N4004**	**1N4005**	**1N4006**	**1N4007**	**UNIT**
Maximum instantaneous forward voltage	1.0 A	V_F	1.1							V
Maximum DC reverse current at rated DC blocking voltage	T_A = 25 °C	I_R	5.5							µA
	T_A = 125 °C		50							
Typical junction capacitance	4.0 V, 1 MHz	C_J	15							pF

THERMAL CHARACTERISTICS (T_A = 25 °C unless otherwise noted)									
PARAMETER	**SYMBOL**	**1N4001**	**1N4002**	**1N4003**	**1N4004**	**1N4005**	**1N4006**	**1N4007**	**UNIT**
Typical thermal resistance	$R_{\theta JA}$ (1)	50							°C/W
	$R_{\theta JL}$ (1)	25							

Note

(1) Thermal resistance from junction to ambient at 0.375" (9.5 mm) lead length, PCB mounted

PACKAGE OUTLINE DIMENSION

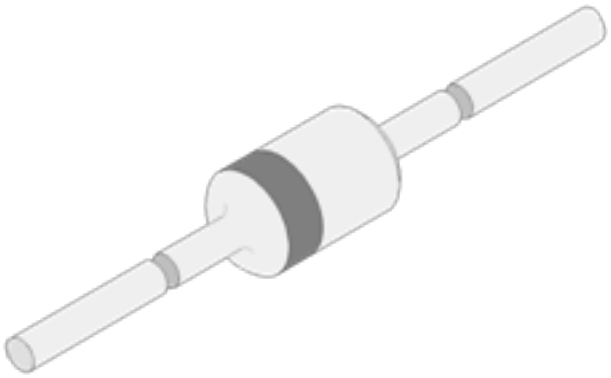


Dimemsion	DO-204AL (DO-41)	
	Min	Max
A	25.40	-
B	4.06	5.21
C	0.71	0.864
D	2.00	2.72
All dimensions in mm		

Silicon Epitaxial Planar Z–Diodes

Features

- Sharp edge in reverse characteristics
- Low reverse current
- Low noise
- Very high stability
- Available with tighter tolerances



Applications

Voltage stabilization

Order Instruction

Type	Ordering Code	Remarks
BZX85C2V7	BZX85C2V7–TAP	Ammopack
	BZX85C2V7–TR	Tape and Reel

Absolute Maximum Ratings

T_j = 25° C

Parameter	Test Conditions	Type	Symbol	Value	Unit
Power dissipation	l=4 mm, T_L=25 °C		P_V	1.3	W
Junction temperature			T_j	175	°C
Storage temperature range			T_{stg}	–65...+175	°C

Maximum Thermal Resistance

T_j = 25° C

Parameter	Test Conditions	Symbol	Value	Unit
Junction ambient	l=4 mm, T_L=constant	R_{thJA}	110	K/W

Electrical Characteristics

T_j = 25° C

Parameter	Test Conditions	Type	Symbol	Min	Typ	Max	Unit
Forward voltage	I_F=200mA		V_F			1	V

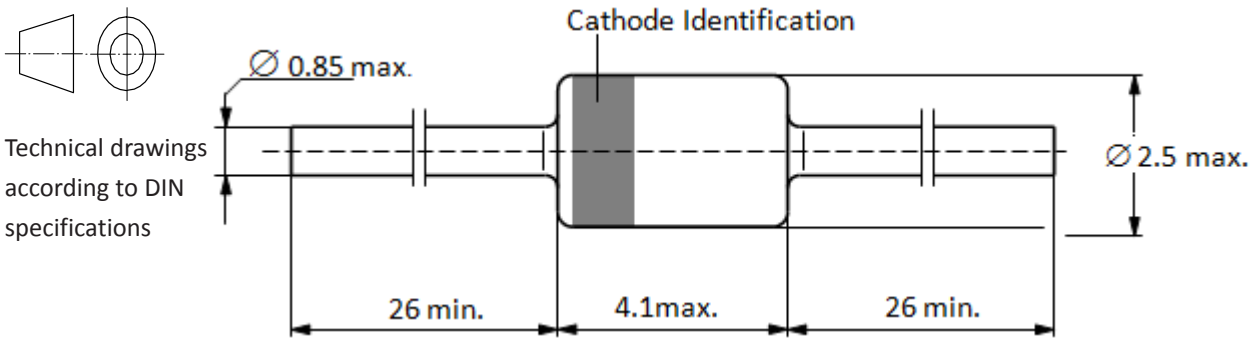
ELECTRICAL CHARACTERISTICS (TA=25°C unless otherwise noted)

Type	Nominal zener voltage	Zener voltage range			Dynamic resistance		Reverse leakage current		Temperature Coefficient of zener voltage
	V_{Znom}	I_{ZT} for V_{ZT} and r_{zjT}			r_{zjk} at I_{ZK}		I_R at V_R		TK_{VZ}
BZX85C...	V	mA	V(1)	Ohm	Ohm	mA	A	V	%/K
BZX85C 2V7	2.7	80	2.5 to 2.9	< 20	< 400	1	< 150	1	–0.08 to –0.05
BZX85C 3V0	3.0	80	2.8 to 3.2	< 20	< 400	1	< 100	1	–0.08 to –0.05
BZX85C 3V3	3.3	80	3.1 to 3.5	< 20	< 400	1	< 40	1	–0.08 to –0.05
BZX85C 3V6	3.6	60	3.4 to 3.8	< 20	< 500	1	< 20	1	–0.08 to –0.05
BZX85C 3V9	3.9	60	3.7 to 4.1	< 15	< 500	1	< 10	1	–0.07 to –0.02
BZX85C 4V3	4.3	50	4.0 to 4.6	< 13	< 500	1	< 3	1	–0.07 to –0.01
BZX85C 4V7	4.7	45	4.4 to 5.0	< 13	< 500	1	< 3	1	–0.03 to +0.04
BZX85C 5V1	5.1	45	4.8 to 5.4	< 10	< 500	1	< 1	1.5	–0.01 to +0.04
BZX85C 5V6	5.6	45	5.2 to 6.0	< 7	< 400	1	< 1	2	0 to +0.045
BZX85C 6V2	6.2	35	5.8 to 6.6	< 4	< 300	1	< 1	3	+0.01 to +0.055
BZX85C 6V8	6.8	35	6.4 to 7.2	< 3.5	< 300	1	< 1	4	+0.015 to +0.06
BZX85C 7V5	7.5	35	7.0 to 7.9	< 3	< 200	0.5	< 1	4.5	+0.02 to +0.065
BZX85C 8V2	8.2	25	7.7 to 8.7	< 5	< 200	0.5	< 1	6.2	0.03 to 0.07
BZX85C 9V1	9.1	25	8.5 to 9.6	< 5	< 200	0.5	< 1	6.8	0.035 to 0.075
BZX85C 10	10	25	9.4 to 10.6	< 7	< 200	0.5	< 0.5	7.5	0.04 to 0.08
BZX85C 11	11	20	10.4 to 11.6	< 8	< 300	0.5	< 0.5	8.2	0.045 to 0.08
BZX85C 12	12	20	11.4 to 12.7	< 9	< 350	0.5	< 0.5	9.1	0.045 to 0.085
BZX85C 13	13	20	12.4 to 14.1	< 10	< 400	0.5	< 0.5	10	0.05 to 0.085
BZX85C 15	15	15	13.8 to 15.6	< 15	< 500	0.5	< 0.5	11	0.055 to 0.09
BZX85C 16	16	15	15.3 to 17.1	< 15	< 500	0.5	< 0.5	12	0.055 to 0.09
BZX85C 18	18	15	16.8 to 19.1	< 20	< 500	0.5	< 0.5	13	0.06 to 0.09
BZX85C 20	20	10	18.8 to 21.2	< 24	< 600	0.5	< 0.5	15	0.06 to 0.09
BZX85C 22	22	10	20.8 to 23.3	< 25	< 600	0.5	< 0.5	16	0.06 to 0.095

BZX85C 24	24	10	22.8 to 25.6	< 25	< 600	0.5	< 0.5	18	0.06 to 0.095
BZX85C 27	27	8	25.1 to 28.9	< 30	< 750	0.25	< 0.5	20	0.06 to 0.095
BZX85C 30	30	8	28 to 32	< 30	< 1000	0.25	< 0.5	22	0.06 to 0.095
BZX85C 33	33	8	31 to 35	< 35	< 1000	0.25	< 0.5	24	0.06 to 0.095
BZX85C 36	36	8	34 to 38	< 40	< 1000	0.25	< 0.5	27	0.06 to 0.095
BZX85C 39	39	6	37 to 41	< 50	< 1000	0.25	< 0.5	30	0.06 to 0.095
BZX85C 43	43	6	40 to 46	< 50	< 1000	0.25	< 0.5	33	0.06 to 0.095
BZX85C 47	47	4	44 to 50	< 90	< 1500	0.25	< 0.5	36	0.06 to 0.095
BZX85C 51	51	4	48 to 54	< 115	< 1500	0.25	< 0.5	39	0.06 to 0.095
BZX85C 56	56	4	52 to 60	< 120	< 2000	0.25	< 0.5	43	0.06 to 0.095
BZX85C 62	62	4	58 to 66	< 125	< 2000	0.25	< 0.5	47	0.06 to 0.095
BZX85C 68	68	4	64 to 72	< 130	< 2000	0.25	< 0.5	51	0.06 to 0.095
BZX85C 75	75	4	70 to 79	< 135	< 2000	0.25	< 0.5	56	0.06 to 0.095

(1) Tighter tolerances available on request: BZX85B... ± 2% of $V_{Z\ nominal}$

Dimensions in mm



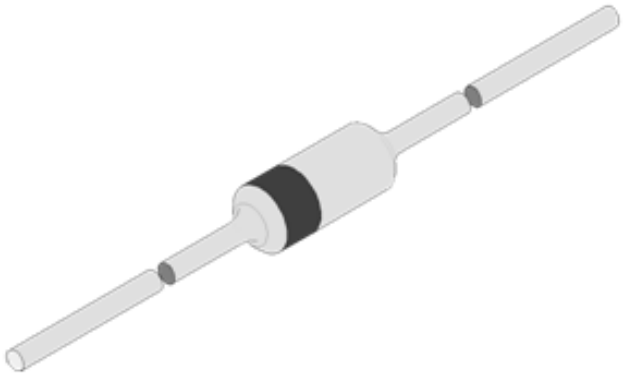
Technical drawings according to DIN specifications

Standard Glass Case 54 B 2 DIN 41880 JEDEC DO 41 Weight max. 0.3 g

Silicon Epitaxial Planar Z–Diodes

Features

- Very sharp reverse characteristic
- Low reverse current level
- Very high stability
- Low noise
- Available with tighter tolerances



Applications

Voltage stabilization

Absolute Maximum Ratings

T_j = 25° C

Parameter	Test Conditions	Type	Symbol	Value	Unit
Power dissipation	l=4mm, T_L=25° C		P_V	500	mW
Z–current			I_Z	P_V/V_Z	mA
Junction temperature			T_j	175	°C
Storage temperature range			T_{stg}	–65...+175	°C

Maximum Thermal Resistance

T_j = 25° C

Parameter	Test Conditions	Symbol	Value	Unit
Junction ambient	l=4mm, T_L=constant	R_{thJA}	300	K/W

Electrical Characteristics

T_j = 25° C

Parameter	Test Conditions	Type	Symbol	Min	Typ	Max	Unit
Forward voltage	I_F=200mA		V_F			1.5	V

Type	V_{Znom}	I_{ZT} for V_{ZT} and r_{zjT}			r_{zjk} at I_{ZK}		I_R and I_R at V_R			TK$_{VZ}$
BZX55C...	V	mA	V (1)	Ohm	Ohm	mA	A	A(2)	V	%/K
BZX55C2V4	2.4	5	2.28 to 2.56	< 85	< 600	1	< 50	< 100	1	–0.09 to –0.06
BZX55C2V7	2.7	5	2.5 to 2.9	< 85	< 600	1	< 10	< 50	1	–0.09 to –0.06
BZX55C3V0	3.0	5	2.8 to 3.2	< 85	< 600	1	< 4	< 40	1	–0.08 to –0.05
BZX55C3V3	3.3	5	3.1 to 3.5	< 85	< 600	1	< 2	< 40	1	–0.08 to –0.05
BZX55C3V6	3.6	5	3.4 to 3.8	< 85	< 600	1	< 2	< 40	1	–0.08 to –0.05
BZX55C3V9	3.9	5	3.7 to 4.1	< 85	< 600	1	< 2	< 40	1	–0.08 to –0.05
BZX55C4V3	4.3	5	4.0 to 4.6	< 75	< 600	1	< 1	< 20	1	–0.06 to –0.03
BZX55C4V7	4.7	5	4.4 to 5.0	< 60	< 600	1	< 0.5	< 10	1	–0.05 to +0.02
BZX55C5V1	5.1	5	4.8 to 5.4	< 35	< 550	1	< 0.1	< 2	1	–0.02 to +0.02
BZX55C5V6	5.6	5	5.2 to 6.0	<25	< 450	1	< 0.1	< 2	1	–0.05 to +0.05
BZX55C6V2	6.2	5	5.8 to 6.6	< 10	< 200	1	< 0.1	< 2	2	0.03 to 0.06
BZX55C6V8	6.8	5	6.4 to 7.2	< 8	< 150	1	< 0.1	< 2	3	0.03 to 0.07
BZX55C7V5	7.5	5	7.0 to 7.9	< 7	< 50	1	< 0.1	< 2	5	0.03 to 0.07
BZX55C8V2	8.2	5	7.7 to 8.7	< 7	< 50	1	< 0.1	< 2	6.2	0.03 to 0.08
BZX55C9V1	9.1	5	8.5 to 9.6	< 10	< 50	1	< 0.1	< 2	6.8	0.03 to 0.09
BZX55C10	10	5	9.4 to 10.6	< 15	< 70	1	< 0.1	< 2	7.5	0.03 to 0.1
BZX55C11	11	5	10.4 to 11.6	< 20	< 70	1	< 0.1	< 2	8.2	0.03 to 0.11
BZX55C12	12	5	11.4 to 12.7	< 20	< 90	1	< 0.1	< 2	9.1	0.03 to 0.11
BZX55C13	13	5	12.4 to 14.1	< 26	< 110	1	< 0.1	< 2	10	0.03 to 0.11
BZX55C15	15	5	13.8 to 15.6	< 30	< 110	1	< 0.1	< 2	11	0.03 to 0.11
BZX55C16	16	5	15.3 to 17.1	< 40	< 170	1	< 0.1	< 2	12	0.03 to 0.11
BZX55C18	18	5	16.8 to 19.1	< 50	< 170	1	< 0.1	< 2	13	0.03 to 0.11
BZX55C20	20	5	18.8 to 21.2	< 55	< 220	1	< 0.1	< 2	15	0.03 to 0.11
BZX55C22	22	5	20.8 to 23.3	< 55	< 220	1	< 0.1	< 2	16	0.04 to 0.12
BZX55C24	24	5	22.8 to 25.6	< 80	< 220	1	< 0.1	< 2	18	0.04 to 0.12
BZX55C27	27	5	25.1 to 28.9	< 80	< 220	1	< 0.1	< 2	20	0.04 to 0.12
BZX55C30	30	5	28 to 32	< 80	< 220	1	< 0.1	< 2	22	0.04 to 0.12
BZX55C33	33	5	31 to 35	< 80	< 220	1	< 0.1	< 2	24	0.04 to 0.12
BZX55C36	36	5	34 to 38	< 80	< 220	1	< 0.1	< 2	27	0.04 to 0.12
BZX55C39	39	2.5	37 to 41	< 90	< 500	0.5	< 0.1	< 5	30	0.04 to 0.12
BZX55C43	43	2.5	40 to 46	< 90	< 600	0.5	< 0.1	< 5	33	0.04 to 0.12
BZX55C47	47	2.5	44 to 50	< 110	< 700	0.5	< 0.1	< 5	36	0.04 to 0.12

BZX55C51	51	2.5	48 to 54	< 125	< 700	0.5	< 0.1	< 10	39	0.04 to 0.12
BZX55C56	56	2.5	52 to 60	< 135	< 1000	0.5	< 0.1	< 10	43	0.04 to 0.12
BZX55C62	62	2.5	58 to 66	< 150	< 1000	0.5	< 0.1	< 10	47	0.04 to 0.12
BZX55C68	68	2.5	64 to 72	< 200	< 1000	0.5	< 0.1	< 10	51	0.04 to 0.12
BZX55C75	75	2.5	70 to 79	< 250	< 1500	0.5	< 0.1	< 10	56	0.04 to 0.12

(1) Tighter tolerances available on request:

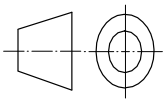
BZX55A... ± 1% of $V_{Znominal}$

BZX55B... ± 2% of $V_{Znominal}$

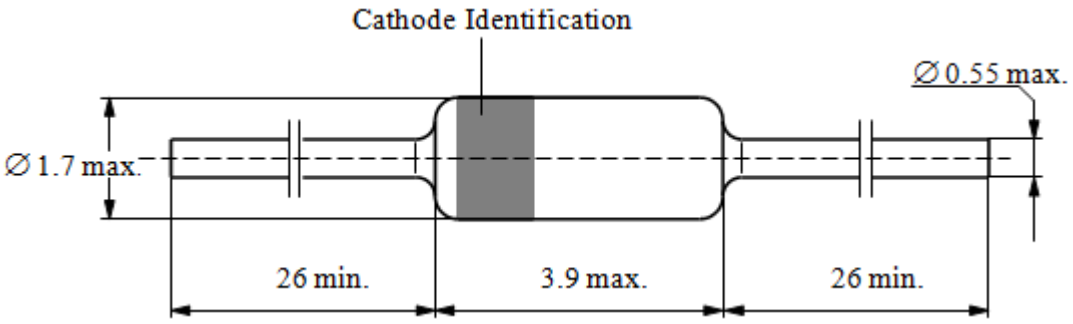
BZX55F... ± 3% of $V_{Znominal}$

(2) at T_j= 150 C

All dimensions in mm



Technical drawings according to DIN specifications



Standard Glass

Case 54 A 2 DIN

41880 JEDEC DO 35

Weight max. 0.3 g

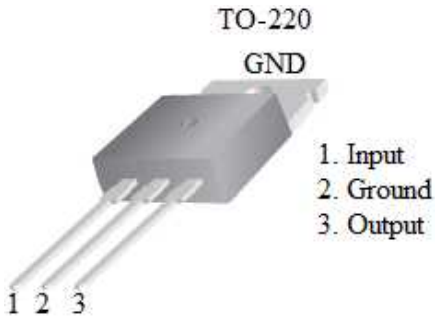
LM78XX/LM78XXA

3-Terminal 1A Positive Voltage Regulator

Features

- Output Current up to 1A
- Output Voltages of 5, 6, 8, 9, 10, 12, 15, 18, 24
- Thermal Overload Protection
- Short Circuit Protection
- Output Transistor Safe Operating Area Protection

Pin assignment



General Description

The LM78XX series of three terminal positive regulators are available in the TO-220 package and with several fixed output voltages, making them useful in a wide range of applications. Each type employs internal current limiting, thermal shut down and safe operating area protection, making it essentially indestructible. If adequate heat sinking is provided, they can deliver over 1A output current. Although designed primarily as fixed voltage regulators, these devices can be used with external components to obtain adjustable voltages and currents.

Absolute Maximum Ratings

Absolute maximum ratings are those values beyond which damage to the device may occur. The datasheet specifications should be met, without exception, to ensure that the system design is reliable over its power supply, temperature, and output/input loading variables. It is not recommend operation outside datasheet specifications. In addition, extended exposure to stresses above the recommended operating conditions may affect device reliability. The absolute maximum ratings are stress rating only. Values are at T_A = 25°C unless otherwise noted.

Symbol	Parameter		Value	Unit
VI	Input Voltage	VO = 5V to 18V	35	V
		VO = 24V	40	V
$R_{\theta JC}$	Thermal Resistance Junction-Cases (TO-220)		5	°C/W
$R_{\theta JA}$	Thermal Resistance Junction-Air (TO-220)		65	°C/W
T_{OPR}	Operating temperature range	LM78XX	-40 to +125	°C
		LM78XXA	0 to +125	
T_{STG}	Storage Temperature Range		-65 to + 150	°C

Electrical Characteristics (**LM7805**)

Refer to the test circuits. -40°C < TJ < 125°C, IO = 500mA, VI = 10V, CI = 0.1µF, unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typical	Max.	Unit
Vo	Output voltage	TJ = +25°C	4.8	5.0	5.2	V
		5mA ≤ IO ≤ 1A, PO ≤ 15W, VI = 7V to 20V	4.75	5.0	5.25	V

Electrical Characteristics (**LM7806**)

Refer to the test circuits. -40°C < TJ < 125°C, IO = 500mA, VI = 11V, CI = 0.33µF, CO = 0.1µF, unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typical	Max.	Unit
Vo	Output voltage	TJ = +25°C	5.75	6.0	6.25	V
		5mA ≤ IO ≤ 1A, PO ≤ 15W, VI = 8.0V to 21V	5.7	6.0	6.3	V

Electrical Characteristics (**LM7808**)

Refer to the test circuits. -40°C < TJ < 125°C, IO = 500mA, VI = 14V, CI = 0.33µF, CO = 0.1µF, unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typical	Max.	Unit
Vo	Output voltage	TJ = +25°C	7.7	8.0	8.3	V
		5mA ≤ IO ≤ 1A, PO ≤ 15W, VI = 10.5V to 23V	7.6	8.0	8.4	V

Electrical Characteristics (**LM7809**)

Refer to the test circuits. -40°C < TJ < 125°C, IO = 500mA, VI = 15V, CI = 0.33µF, CO = 0.1µF, unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typical	Max.	Unit
Vo	Output voltage	TJ = +25°C	8.65	9.0	9.35	V
		5mA ≤ IO ≤ 1A, PO ≤ 15W, VI = 11.5V to 24V	8.6	9.0	9.4	V

Electrical Characteristics (**LM7810**)

Refer to the test circuits. -40°C < TJ < 125°C, IO = 500mA, VI = 16V, CI = 0.33µF, CO = 0.1µF, unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typical	Max.	Unit
Vo	Output voltage	TJ = +25°C	9.6	10.0	10.4	V
		5mA ≤ IO ≤ 1A, PO ≤ 15W, VI = 12.5V to 25V	9.5	10.0	10.5	V

Electrical Characteristics (**LM7812**) (Continued)

Refer to the test circuits. -40°C < TJ < 125°C, IO = 500mA, VI = 19V, CI = 0.33µF, CO = 0.1µF, unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typical	Max.	Unit
Vo	Output voltage	TJ = +25°C	11.5	12.0	12.5	V
		5mA ≤ IO ≤ 1A, PO ≤ 15W, VI = 14.5V to 27V	11.4	12.0	12.6	V

Electrical Characteristics (**LM7815**)

Refer to the test circuits. -40°C < TJ < 125°C, IO = 500mA, VI = 23V, CI = 0.33µF, CO = 0.1µF, unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typical	Max.	Unit
Vo	Output voltage	TJ = +25°C	14.4	15.0	15.6	V
		5mA ≤ IO ≤ 1A, PO ≤ 15W, VI = 17.5V to 30V	14.25	15.0	15.75	V

Electrical Characteristics (**LM7818**)

Refer to the test circuits. -40°C < TJ < 125°C, IO = 500mA, VI = 27V, CI = 0.33µF, CO = 0.1µF, unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typical	Max.	Unit
Vo	Output voltage	TJ = +25°C	17.3	18.0	18.7	V
		5mA ≤ IO ≤ 1A, PO ≤ 15W, VI = 21V to 33V	17.1	18.0	18.9	V

Electrical Characteristics (**LM7824**)

Refer to the test circuits. -40°C < TJ < 125°C, IO = 500mA, VI = 33V, CI = 0.33µF, CO = 0.1µF, unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typical	Max.	Unit
Vo	Output voltage	TJ = +25°C	23.0	24.0	25.0	V
		5mA ≤ IO ≤ 1A, PO ≤ 15W, VI = 27V to 38V	22.8	24.0	25.25	V

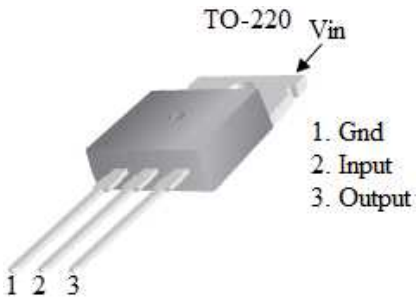
- These parameters, although guaranteed, are not 100% tested in production.

LM79XX

3-Terminal 1A Negative Voltage Regulator

Features

- Output Current in Excess of 1A
- Output Voltages of -5, -6, -8 , -9, -10, -12, -15, -18 and -24V
- Internal Thermal Overload Protection
- Short Circuit Protection
- Output Transistor Safe Operating Area Compensation



Description

The LM79XX series of three terminal negative regulators are available in TO-220 package and with several fixed output voltages, making them useful in a wide range of applications. Each type employs internal current limiting, thermal shut down and safe operating area protection, making it essentially indestructible.

Parameter	Symbol	Value	Unit
Input Voltage	VI	-35	V
Thermal Resistance Junction-Cases (note 1)	$R_{\theta JC}$	5	°C/W
Thermal Resistance Junction-Air (note 1,2)	$R_{\theta JA}$	65	
Operating Temperature Range	T_{OPR}	0 ~ +125	°C
Storage Temperature Range	T_{STG}	-65 ~ +150	°C

Note:

1. Thermal resistance test board
   Size: 76.2mm * 114.3mm * 1.6mm (1S0P)
   JEDEC standard: JESD51-3, JESD51-7
2. Assume no ambient airflow

Electrical Characteristics (LM7905)

(V_I = -10V, I_O = 500mA, 0°C ≤T_J ≤ +125°C, C_I =2.2µF, C_O =1µF, unless otherwise specified.)

Symbol	Parameter	Conditions	Min.	Typical	Max.	Unit
Vo	Output voltage	T_J = +25°C	-4.8	-5.0	-5.2	V
		I_O = 5mA to 1A, P_O ≤ 15W V_I = -7V to -20V	-4.75	-5.0	-5.25	

Electrical Characteristics (LM7906)

(V_I = -11V, I_O = 500mA, 0°C ≤T_J ≤ +125°C, C_I =2.2µF, C_O =1µF, unless otherwise specified.)

Symbol	Parameter	Conditions	Min.	Typical	Max.	Unit
Vo	Output voltage	T_J = +25°C	-5.75	-6.0	-6.25	V
		I_O = 5mA to 1A, P_O ≤ 15W V_I = -9V to -21V	-5.7	-6.0	-6.3	

Electrical Characteristics (LM7908)

(V_I = -14V, I_O = 500mA, 0°C ≤T_J ≤ +125°C, C_I =2.2µF, C_O =1µF, unless otherwise specified.)

Symbol	Parameter	Conditions	Min.	Typical	Max.	Unit
Vo	Output voltage	T_J = +25°C	-7.7	-8.0	-8.3	V
		I_O = 5mA to 1A, P_O ≤ 15W V_I = -10V to -23V	-7.6	-8.0	-8.4	

Electrical Characteristics (LM7909)

(V_I = -15V, I_O = 500mA, 0°C ≤T_J ≤ +125°C, C_I =2.2µF, C_O =1µF, unless otherwise specified.)

Symbol	Parameter	Conditions	Min.	Typical	Max.	Unit
Vo	Output voltage	T_J = +25°C	-8.7	-9.0	-9.3	V
		I_O = 5mA to 1A, P_O ≤ 15W V_I = -1.5V to -23V	-8.6	-9.0	-9.4	

Electrical Characteristics (LM7910)

(V_I = -17V, I_O = 500mA, 0°C ≤T_J ≤ +125°C, C_I =2.2µF, C_O =1µF, unless otherwise specified.)

Symbol	Parameter	Conditions	Min.	Typical	Max.	Unit
Vo	Output voltage	T_J = +25°C	-9.6	-10	-10.4	V
		I_O = 5mA to 1A, P_d ≤ 15W V_I = -12V to -28	-9.5	-10	-10.5	

Electrical Characteristics (LM7912)

(V_I = -19V, I_O = 500mA, 0°C ≤T_J ≤ +125°C, C_I =2.2µF, C_O =1µF, unless otherwise specified.)

Symbol	Parameter	Conditions	Min.	Typical	Max.	Unit
Vo	Output voltage	T_J = +25°C	-11.4	-12	-12.5	V
		I_O = 5mA to 1A, P_O ≤ 15W V_I = -15.5V to -27V	-11.4	-12	-12.6	

Electrical Characteristics (LM7915)

(V_I = -23V, I_O = 500mA, 0°C ≤T_J ≤ +125°C, C_I =2.2µF, C_O =1µF, unless otherwise specified.)

Symbol	Parameter	Conditions	Min.	Typical	Max.	Unit
Vo	Output voltage	T_J = +25°C	-14.4	-15	-15.6	V
		I_O = 5mA to 1A, P_O ≤ 15W V_I = -18V to -30V	-14.25	-15	-15.75	

Electrical Characteristics (LM7918)

(V_I = -27V, I_O = 500mA, 0°C ≤T_J ≤ +125°C, C_I =2.2µF, C_O =1µF, unless otherwise specified.)

Symbol	Parameter	Conditions	Min.	Typical	Max.	Unit
Vo	Output voltage	T_J = +25°C	-17.3	-18	-18.7	V
		I_O = 5mA to 1A, P_O ≤ 15W V_I = -22.5V to -33V	-17.1	-18	-18.9	

Electrical Characteristics (LM7924)

(V_I = -33V, I_O = 500mA, 0°C ≤T_J ≤ +125°C, C_I =2.2µF, C_O =1µF, unless otherwise specified.)

Symbol	Parameter	Conditions	Min.	Typical	Max.	Unit
Vo	Output voltage	T_J = +25°C	-23	-24	-25	V
		I_O = 5mA to 1A, P_O ≤ 15W V_I = -27V to -38V	-22.8	-24	-25.2	

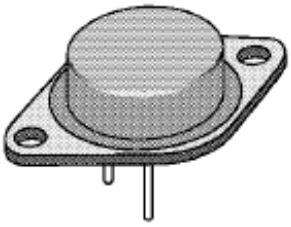
SGS-THOMSON MICROELECTRONICS

LM137/LM237 LM337

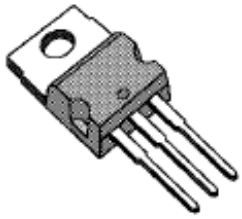
THREE-TERMINAL ADJUSTABLE NEGATIVE VOLTAGE REGULATORS

Features

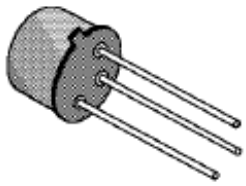
- OUTPUT VOLTAGE ADJUSTABLE DOWN TO Vref
- 1.5A GUARANTEED OUTPUT CURRENT
- 0.3%/V TYPICAL LOAD REGULATION
- 0.01%/V TYPICAL LINE REGULATION CURRENT LIMIT CONSTANT WITH TEMPERATURE
- RIPPLE REJECTION: 77dB
- STANDARD 3-LEAD TRANSISTOR PACKAGES
- EXCELLENT THERMAL REGULATION:0.002% /V
- 50ppm/°C TEMPERATURE COEFFICIENT



TO-3



TO-220

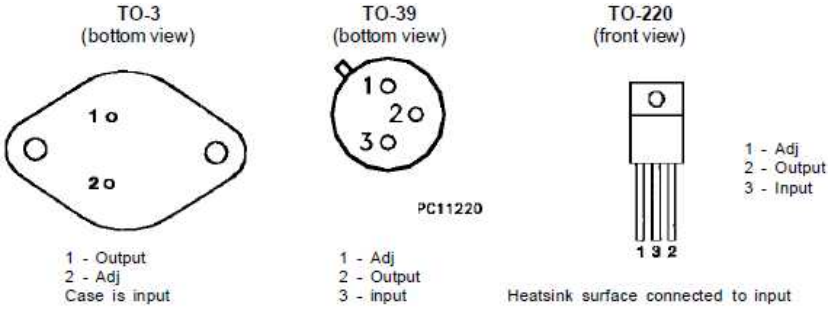


TO-39

DESCRIPTION

The LM137 series are adjustable 3-terminal negative voltage regulators capable of supplying in excess - 1.5A over a - 1.2 to - 37V output voltage range. They are exceptionally easy to use and require only two external resistors to set the output voltage. Further, both line and load regulation are better than standard fixed regulators. Also, LM137 regulators are supplied in standard transistor packages which are easily mounted and handled. In addition to higher performance than fixed regulators, the LM137 series offer full overload protection available only in integrated circuits. Included on the chip are current limit, thermal overload protection and safe area protection. All overload protection circuitry remains fully functional even if the adjustment terminal is disconnected.

PIN Configulation



ABSOLUTE MAXIMUM RATING

Symbol	Parameter		Value	Unit
$V_I - V_O$	Input Output Voltage Differential		40	V
Io	Output current	TO-220/TO-3	1.5	Q
		TO-39	0.5	
Tstg		LM137	-55 to 150	°C
		LM237	-25 to 150	
		LM337	0 to 125	
Tstg			-65 to 150	°C
Ptot			Internally limited	W

THERMAL CHARACTERISTICS

Symbol	Parameter		Typ.	Max.	Unit
Rthj-case	Junction-case Thermal Resistance	T-3		4	°C/W
		TO-220		3	
		TO-39		15	
Rthj-amb	Junction-ambient Thermal Resistance	TO-3		35	°C/W
		TO-220		70	
		TO-39		160	

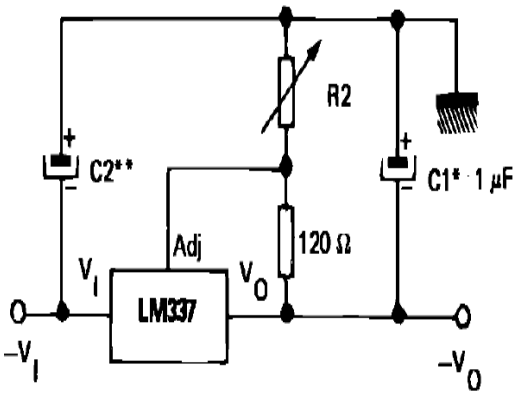
ORDER CODES

PART NUMBER	TEMPERATURE RANGE	PACKAGE		
		TO-3	TO-220	TO-39
LM137	-55 to 150 °C	LM137K		LM137H
LM237	-25 to 150 °C	LM237K	LM237SP	LM237H
LM337	0 to 125 °C	LM337K	LM337SP	LM337H

ELECTRICAL CHARACTERISICS

LM137: -55 °C < Tj < 150 °C
LM237: -25 °C < Tj < 150 °C
LM337: 0 °C < Tj < 150 °C
$V_I - V_O$ = 5V, I_O = 0.5 A (unless otherwise specified)

Typical application



Vout = - 1.25V(1+R2/120) + (-IADJ*R2)

Symbol	Parameter	LM137/LM237			LM337			Unit
		Min.	Typ.	Max.	Min.	Typ.	Max.	
V_{ref}	Reference Voltage T_{amb} = 25 °C $T_{min} \le T_j \le T_{max}$ $3V \le \lvert V_i - V_o \rvert \le 40V$, $10mA \le \lvert I_o \rvert \le \lvert I_{o(max)} \rvert$ $P \le P_{max}$	-1.225 -1.2	-1.25 -1.25	-1.275 -1.3	-1.213 -1.2	-1.25 -1.25	-1.287 -1.3	V
K_{VI}	Line Regulation (T_{amb} = 25 °C, $3V \le \lvert V_i - V_o \rvert \le 40V$) - Note 2 I_o = 0.1 A I_o = 20 mA		 0.01 0.01	 0.02 0.02		 0.01 0.01	 0.04 0.04	 %/V %/V
K_{VO}	Load Regulation (T_{amb} = 25 °C, $10mA \le \lvert I_o \rvert \le \lvert I_{o(max)} \rvert$) - Note 2 $\lvert V_o \rvert \le 5V$ $\lvert V_o \rvert \ge 5V$		 15 0.3	 25 0.5		 15 0.3	 50 1	 mV %
	Thermal Regulation (T_{amb} = 25 °C, pulse 10 ms)		0.002	0.02		0.003	0.04	%/W
I_{adj}	Adjustment Pin Current		65	100		65	100	µA
ΔI_{adj}	Adjustment Pin Current Change (T_{amb} = 25 °C, $10mA \le \lvert I_o \rvert \le \lvert I_{o(max)} \rvert$, $3V \le \lvert V_i - V_o \rvert \le 40V$)		2	5		2	5	µA
K_{VI}	Line Regulation ($3V \le \lvert V_i - V_o \rvert \le 40V$) - Note 2		0.02	0.05		0.02	0.07	%/V
K_{VO}	Load Regulation ($10mA \le \lvert I_o \rvert \le \lvert I_{o(max)} \rvert$) - Note 2 $\lvert V_o \rvert \le 5V$ $\lvert V_o \rvert \ge 5V$		 20 0.3	 50 1		 20 0.3	 70 1.5	 mV %
$\lvert I_{o(min)} \rvert$	Minimum Load Current $\lvert V_i - V_o \rvert \le 40V$ $\lvert V_i - V_o \rvert \le 10V$		 2.5 1.2	 5 3		 2.5 1.5	 10 6	 mA mA
I_{OS}	Short Circuit Output Current $\lvert V_i - V_o \rvert \le 15V$ (TO-3 and TO-220) $\lvert V_i - V_o \rvert \le 15V$ (TO-39) $\lvert V_i - V_o \rvert = 40V$, T_j = 25 °C (TO-3 and TO-220) $\lvert V_i - V_o \rvert = 40V$, T_j = 25 °C (TO-39)	 1.5 0.5 0.24 0.15	 2.2 0.4 0.2		 1.5 0.5 0.15 0.1	 2.2 0.4 0.2		 A A A A
V_{NO}	RMS Output Noise (% of V_o) T_{amb} = 25 °C, 10Hz ≤ f ≤ 10KHz		0.003			0.003		%
R_{vf}	Ripple Rejection Ratio V_o = - 10 V, f = 120 Hz C_{adj} = 10 µF	 66	 60 77		 66	 60 77		 dB dB
K_{VT}	Temperature Stability		0.6			0.6		%
K_{VH}	Long Term Stability (T_{amb} = 125 °C, 1000H)		0.3	1		0.3	1	%

Notes :

1. Although power dissipation is internally limited, these specifications are applicable for power dissipation of :

- 2W for TO-39
- 15W for TO-220
- 20W for TO-3 Package

IO(max) is :

- 1.5A for TO-3 and TO-220
- 0.5A for TO-39

2. Regulation is measured at constant junction temperature, using pulse testing with a low duty cycle. Changes in output voltage due to heating effects are covered under the specification for thermal regulation.

LM117, LM317A, LM317-N Three-Termianl Adjustable Regulator

FEATURES

- Specified 1% Output Voltage Tolerance (LM317A)
- Specified max. 0.01%/V Line Regulation (LM317A)
- Specified max. 0.3% Load Regulation (LM117)
- Specified 1.5A Output Current
- Adjustable Output Down to 1.2V
- Current Limit Constant with Temperature
- P+ Product Enhancement tested
- 80 dB Ripple Rejection
- Output is Short-Circuit Protected

DESCRIPTION

The LM117 series of adjustable 3-terminal positive voltage regulators is capable of supplying in excess of 1.5A over a 1.2V to 37V output range. They are exceptionally easy to use and require only two external resistors to set the output voltage. Further, both line and load regulation are better than standard fixed regulators. Also, the LM117 is packaged in standard transistor packages which are easily mounted and handled.

In addition to higher performance than fixed regulators, the LM117 series offers full overload protection available only in IC's. Included on the chip are current limit, thermal overload protection and safe area protection. All overload protection circuitry remains fully functional even if the adjustment terminal is disconnected.

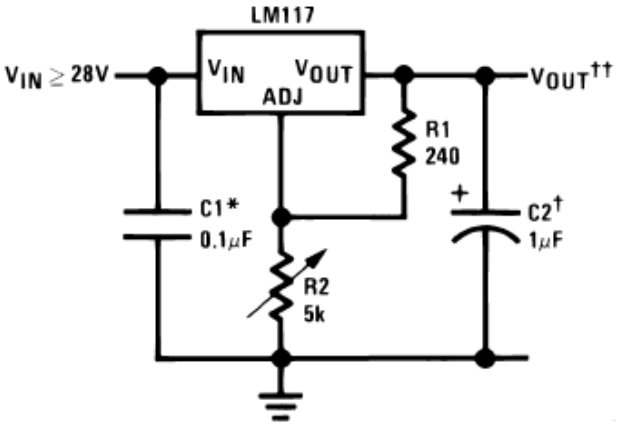
Normally, no capacitors are needed unless the device is situated more than 6 inches from the input filter capacitors in which case an input bypass is needed. An optional output capacitor can be added to improve transient response. The adjustment terminal can be bypassed to achieve very high ripple rejection ratios which are difficult to achieve with standard 3-terminal regulators.

Besides replacing fixed regulators, the LM117 is useful in a wide variety of other applications. Since the regulator is "floating" and sees only the input-to-output differential voltage, supplies of several hundred volts can be regulated as long as the maximum input to output differential is not exceeded, i.e., avoid short-circuiting the output.

Also, it makes an especially simple adjustable switching regulator, a programmable output regulator, or by connecting a fixed resistor between the adjustment pin and output, the LM117 can be used as a precision current regulator. Supplies with electronic shutdown can be achieved by clamping the adjustment terminal to ground which programs the output to 1.2V where most loads draw little current.

For applications requiring greater output current, see LM150 series (3A) and LM138 series (5A) data sheets. For the negative complement, see LM137 series data sheet.

Typical Application



Full output current not available at high input-output voltages

*Needed if device is more than 6 inches from filter capacitors.

†Optional—improves transient response. Output capacitors in the range of 1 µF to 1000 µF of aluminum or tantalum electrolytic are commonly used to provide improved output impedance and rejection of transients.

††Vout = 1.25V(1+R2/R1) + IADJ(R2)

LM117/LM317A/LM317-N Package Options

Part Number	Package Drawing	Package Type	Output Current
LM117K STEEL	NDS	TO-3	1.5A
LM317K			
LM317AT	NDE	TO-220	
LM317T			
LM317T/LF01	NDG		
LM317S	KTT	TO-263	
LM317AEMP	DCY	SOT-223	1.0A
LM317EMP			
LM117H	NDT	TO	0.5A
LM317AH			
LM317H			
LM317AMDT	NDP	TO-252	
LM317MDT			

ABSOLUTE MAXIMUM RATINGS (1)(2)

Power Dissipation		Internally Limited
Input-Output Voltage Differential		+40V, −0.3V
Storage Temperature		−65°C to +150°C
Lead Temperature	Metal Package (Soldering, 10 seconds)	300°C
	Plastic Package (Soldering, 4 seconds)	260°C
ESD Tolerance (3)		3 kV

(1) Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not ensure specific performance limits. For ensured specifications and test conditions, see the Electrical Characteristics. The ensured specifications apply only for the test conditions listed.

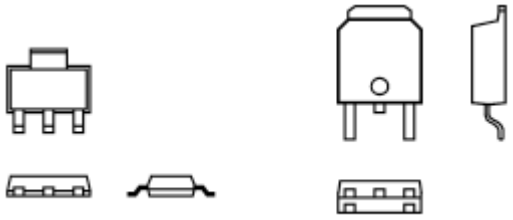
(2) If Military/Aerospace specified devices are required, please contact the Texas Instruments Sales Office/ Distributors for availability and specifications.

(3) Human body model, 100 pF discharged through a 1.5 kΩ resistor.

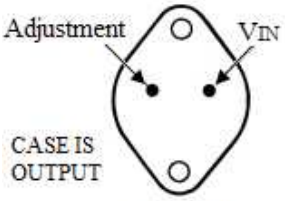
OPERATING TEMPERATURE RANGE

LM117	−55°C ≤ TJ ≤ +150°C
LM317A	−40°C ≤ TJ ≤ +125°C
LM317-N	0°C ≤ TJ ≤ +125°C
Preconditioning	
Thermal Limit Burn-In	All Devices 100%

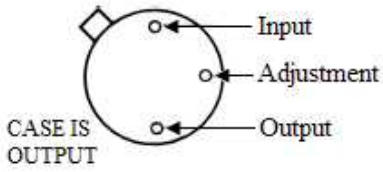
SOT-223 vs TO-252 Packages



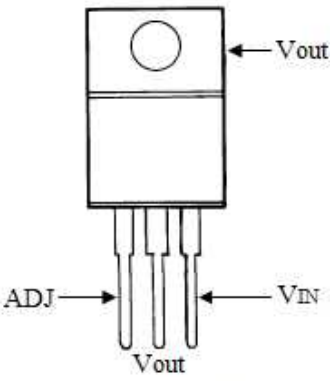
Connection diagrams



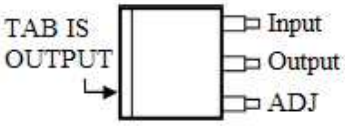
TO-3 (NDS)
Metal Can Package
Bottom View
Package Drawing NDS



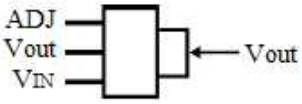
TO (NDT)
Metal Can Package
Bottom View
Package Drawing NDT



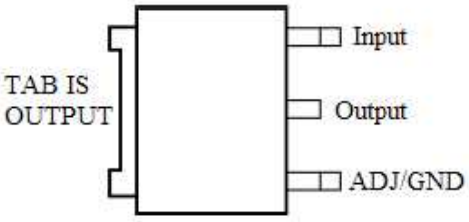
TO-220 (NDE)
Plastic Package
Front View
Package Drawing NDE



TO-263 (KTT)
Surface-Mount Package
Top View
Package Drawing KTT



4-Lead SOT-223 (DCY)
Top View Surface-Mount Package
Package Number DCY



TO-252 (NDP)
Front View Surface Mount Package
Package Drawing NDP

LM117 ELECTRICAL CHARACTERISTICS[1]

Specifications with standard type face are for T_J = 25°C, and those with **boldface type** apply over **full Operating Temperature Range**. Unless otherwise specified, $V_{IN} - V_{OUT}$ = 5V, and I_{OUT} = 10 mA.

Parameter	Conditions		LM117 [2] Min.	Typ.	Max.	Units
Reference Voltage	3V ≤ ($V_{IN} - V_{OUT}$) ≤ 40V, 10 mA ≤ I_{OUT} ≤ I_{MAX}[1]		**1.20**	**1.25**	**1.30**	V
Line Regulation	3V ≤ ($V_{IN} - V_{OUT}$) ≤ 40V [3]			0.01 **0.02**	0.02 **0.05**	%/V
Load Regulation	10 mA ≤ I_{OUT} ≤ I_{MAX}[1] [3]			0.1 **0.3**	0.3 **1**	%
Thermal Regulation	20 ms Pulse			0.03	0.07	%/W
Adjustment Pin Current				**50**	**100**	µA
Adjustment Pin Current Change	10 mA ≤ I_{OUT} ≤ I_{MAX}[1] 3V ≤ ($V_{IN} - V_{OUT}$) ≤ 40V			**0.2**	**5**	µA
Temperature Stability	$T_{MIN} \le T_J \le T_{MAX}$			**1**		%
Minimum Load Current	($V_{IN} - V_{OUT}$) = 40V			**3.5**	**5**	mA
Current Limit	($V_{IN} - V_{OUT}$) ≤ 15V	NDS Package	**1.5**	**2.2**	**3.4**	A
		NDT Package	**0.5**	**0.8**	**1.8**	
	($V_{IN} - V_{OUT}$) = 40V	NDS Package	0.3	0.4		A
		NDT Package	0.15	0.20		
RMS Output Noise, % of V_{OUT}	10 Hz ≤ f ≤ 10 kHz			0.003		%
Ripple Rejection Ratio	V_{OUT} = 10V, f = 120 Hz, C_{ADJ} = 0 µF			**65**		dB
	V_{OUT} = 10V, f = 120 Hz, C_{ADJ} = 10 µF		**66**	**80**		dB
Long-Term Stability	T_J = 125°C, 1000 hrs			0.3	1	%
Thermal Resistance, θ_{JC} Junction-to-Case	NDS (TO-3) Package			2		°C/W
	NDT (TO) Package			21		
Thermal Resistance, θ_{JA} Junction-to-Ambient (No Heat Sink)	NDS (TO-3) Package			39		°C/W
	NDT (TO) Package			186		

(1) I_{MAX} = 1.5A for the NDS (TO-3), NDE (TO-220), and KTT (TO-263) packages. I_{MAX} = 1.0A for the DCY (SOT-223) package. I_{MAX} = 0.5A for the NDT (TO) and NDP (TO-252) packages. Device power dissipation (P_D) is limited by ambient temperature (T_A), device maximum junction temperature (T_J), and package thermal resistance (θ_{JA}). The maximum allowable power dissipation at any temperature is : $P_{D(MAX)} = ((T_{J(MAX)} - T_A)/\theta_{JA})$. All Min. and Max. limits are ensured to TI's Average Outgoing Quality Level (AOQL).

(2) Specifications and availability for military and space grades of LM117/883 can be found in the LM117QML datasheet (SNVS356).

Specifications and availability for military and space grades of LM117/JAN can be found in the LM117JAN datasheet (SNVS365).

(3) Regulation is measured at a constant junction temperature, using pulse testing with a low duty cycle. Changes in output voltage due to heating effects are covered under the specifications for thermal regulation.

LM317A and LM317-N ELECTRICAL CHARACTERISTICS(1)

Specifications with standard type face are for T_J = 25°C, and those with **boldface type** apply over **full Operating Temperature Range**. Unless otherwise specified, $V_{IN} - V_{OUT}$ = 5V, and I_{OUT} = 10 mA.

Parameter	Conditions		LM317A			LM317-N			Units
			Min	Typ	Max	Min	Typ	Max	
Reference Voltage			1.238	1.250	1.262	-	1.25	-	V
	3V ≤ ($V_{IN} - V_{OUT}$) ≤ 40V, 10 mA ≤ I_{OUT} ≤ I_{MAX}(1)		**1.225**	**1.250**	**1.270**	**1.20**	**1.25**	**1.30**	V
Line Regulation	3V ≤ ($V_{IN} - V_{OUT}$) ≤ 40V (2)			0.005 **0.01**	0.01 **0.02**		0.01 **0.02**	0.04 **0.07**	%/V
Load Regulation	10 mA ≤ I_{OUT} ≤ I_{MAX}(1) (2)			0.1 **0.3**	0.5 **1**		0.1 **0.3**	0.5 **1.5**	%
Thermal Regulation	20 ms Pulse			0.04	0.07		0.04	0.07	%/W
Adjustment Pin Current				**50**	**100**		**50**	**100**	µA
Adjustment Pin Current Change	10 mA ≤ I_{OUT} ≤ I_{MAX}(1) 3V ≤ ($V_{IN} - V_{OUT}$) ≤ 40V			**0.2**	**5**		**0.2**	**5**	µA
Temperature Stability	$T_{MIN} \le T_J \le T_{MAX}$			**1**			**1**		%
Minimum Load Current	($V_{IN} - V_{OUT}$) = 40V			**3.5**	**10**		**3.5**	**10**	mA
Current Limit	($V_{IN} - V_{OUT}$) ≤ 15V	NDS, KTT Packages	-	-	-	**1.5**	**2.2**	**3.4**	A
		DCY, NDE Packages	**1.5**	**2.2**	**3.4**	**1.5**	**2.2**	**3.4**	
		NDT Package	**0.5**	**0.8**	**1.8**	**0.5**	**0.8**	**1.8**	
	($V_{IN} - V_{OUT}$) = 40V	NDS, KTT Packages	-	-		0.15	0.40		A
		DCY, NDE Packages	0.15	0.40		0.15	0.40		
		NDT Package	0.075	0.20		0.075	0.20		
RMS Output Noise, % of V_{OUT}	10 Hz ≤ f ≤ 10 kHz			0.003			0.003		%
Ripple Rejection Ratio	V_{OUT} = 10V, f = 120 Hz, C_{ADJ} = 0 µF			**65**			**65**		dB
	V_{OUT} = 10V, f = 120 Hz, C_{ADJ} = 10 µF		**66**	**80**		**66**	**80**		dB
Long-Term Stability	T_J = 125°C, 1000 hrs			0.3	1		0.3	1	%

Thermal Resistance, θ_{JC} Junction-to-Case	NDS (TO-3) Package		-			2		°C/W
	NDE (TO-220) Package		4			4		
	KTT (TO-263) Package		-			4		
	DCY (SOT-223) Package		23.5			23.5		
	NDT (TO) Package		21			21		
	NDP (TO-252) Package		12			12		
Thermal Resistance, θ_{JA} Junction-to-Ambient (No Heat Sink)	NDS (TO-3) Package		-			39		°C/W
	NDE (TO-220) Package	50			50			
	KTT (TO-263) Package (3)		-			50		
	DCY (SOT-223) Package (3)		140			140		
	NDT (TO) Package		186			186		
	NDP (TO-252) Package (3)		103			103		

(1) I_{MAX} = 1.5A for the NDS (TO-3), NDE (TO-220), and KTT (TO-263) packages. I_{MAX} = 1.0A for the DCY (SOT-223) package. I_{MAX} = 0.5A for the NDT (TO) and NDP (TO-252) packages. Device power dissipation (P_D) is limited by ambient temperature (T_A), device maximum junction temperature (T_J), and package thermal resistance (θ_{JA}). The maximum allowable power dissipation at any temperature is : $P_{D(MAX)} = ((T_{J(MAX)} - T_A)/\theta_{JA})$. All Min. and Max. limits are ensured to TI's Average Outgoing Quality Level (AOQL).

(2) Regulation is measured at a constant junction temperature, using pulse testing with a low duty cycle. Changes in output voltage due to heating effects are covered under the specifications for thermal regulation.

(3) When surface mount packages are used (TO-263, SOT-223, TO-252), the junction to ambient thermal resistance can be reduced by increasing the PC board copper area that is thermally connected to the package.